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(NASA-CR-129797) ON MULTIDISCIPLINARY
RESEARCH ON THE APPLICATION OF REMOTE
SENSING TO WATER RESOURCES PROBLEMS
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On Multidisciplinary Research On The
Application Of Remote Sensing To
Water Resources Problems

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1971-1972

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from

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I. INTRODUCTION

This is a progress report on NASA's grant to the University of Wisconsin for Multidisciplinary Research in Space Science and Engineering. During the 1971-72 period the project was focused upon the problem of applying remote sensing techniques to the solution of water resources problems.

The need for applying remote sensing techniques to develop a monitoring system is present in almost all aspects of water resources problems. This particularly holds true for the problems we have focused upon: 1) Water Pollution Monitoring, 2) Effluent Mixing Zone Modeling, 3) Current and Circulation Modeling, 4) Determination of Hydrologically Active Source Areas, and 5) Aquatic Ecosystems Analysis.

Fundamental objectives of research conducted during the 1971-72 period were:

(1) To ascertain the extent to which special aerial photography can be operationally used in monitoring water pollution parameters through a comparison of photo imagery and actual pollution conditions.

(2) To develop a relationship between the extent of the "mixing zone" in terms of outfall, effluent, and water body characteristics by utilizing the imagery obtained from intensive aerial remote sensing and applying the derived data in duplicating the "mixing zone" characteristics in a series of laboratory model studies. The main objective can then be realized in developing a reasonable sampling and regulation program for waste effluent discharges in cooperation with State and Federal governmental agencies.

(3) To determine the fine scale structure and efficiency of nearshore circulation patterns in the Great Lakes through the use of thermal scanning imagery and analytic photogrammetric techniques. The construction of mathematical models can then follow, and the predictions made from them can be used to make reassured decisions regarding sewage outfall, water intakes or power plant siting.

(4) To develop a remote sensing technique for determining the location and extent of source areas in a watershed.

(5) (A). To use remote sensing in the development of a production model for Myriophyllum spicatum L. in Lake Wingra.

(B). To evaluate the field potential of remote sensing techniques in detecting the occurrence, intensity, duration and composition of algal blooms in the Madison, Wisconsin, area lakes.

The remote sensing program is related to other programs through the participation of the principal investigators in other

research projects. It is related to programs at the University of Wisconsin as well as of other State and Federal agencies, including the International Biological Program and the University's Marine Studies Center (which are funded by NSF), the State of Wisconsin Department of Natural Resources, and the U.S. Attorney's Office. Because of the interaction between the remote sensing program and these other related projects and agencies, the program is administered by the University of Wisconsin Institute for Environmental Studies, in the Environmental Monitoring and Data Acquisition Group, which is specifically designed to accommodate this type of interdisciplinary approach.

II. APPLICATION OF REMOTE SENSING TO THE DETERMINATION OF WATER QUALITY

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James P. Scherz, Associate Professor of Civil and Environmental Engineering

Francis H. Schraufnagel, Dept. of Natural Resources, State of Wisconsin

ABSTRACT

This research is directed toward development of a practical, operational remote sensing water quality monitoring system. To accomplish this, five fundamental aspects of the problem have been under investigation during the past three years. These are: 1) development of practical and economical methods of obtaining, handling and analyzing remote sensing data; 2) determination of the correlation between remote sensed imagery and actual water quality parameters; 3) determination of the optimum technique for monitoring specific water pollution parameters and for evaluating the reliability with which this can be accomplished; 4) determination of the extent of masking due to depth of penetration, bottom effects, film development effects, and angle falloff, and development of techniques to eliminate or minimize them; and 5) development of operational procedures which might be employed by a municipal, state or federal agency for the application of remote sensing to water quality monitoring, including space-generated data.

Satisfactory results, at least in a general sense, have been achieved for the first four aspects of the problem as listed above. Primary emphasis is now being placed upon the fifth aspect of the problem, namely, the development of operational procedures. This requires, in some cases, refinements to the results obtained under the first four aspects of the problem.

A. PRESENT STATUS OF INVESTIGATION

First aspect of the problem of developing a practical remote sensing water quality monitoring system to be investigated was the development of practical and economical methods of obtaining, handling and analyzing remote sensing data. A summary of this portion of the work is shown in Table I.

Results indicate that a bulk 35mm microfilm camera system, coupled with microfilm indexing and viewing systems and micro-densitometer-spectrophotometer analysis equipment, provides the

TABLE I
METHODS OF OBTAINING, HANDLING AND ANALYZING
REMOTE SENSING WATER QUALITY IMAGERY

A. AERIAL CAMERAS

- | | |
|---|--|
| 1. 9x9 inch format | Excellent resolution, but very expensive, especially for simultaneous multiband work. Neither portable nor versatile. View on light tables or by prints. |
| 2. 7x7 inch format | Good quality images, but bulky and not very portable or versatile. View on a light table or with prints. |
| 3. 70mm format | Good quality image, good for multi-band work with a large plane belly hole. Not portable for hand-held operation. View on light table. |
| 4. 35mm slide camera | The most economical and versatile method for hand-held and belly hole operation from various aircraft. View with slide projectors. Resolution satisfactory. Chief disadvantage is that slides get mixed up and lost. |
| 5. 35mm bulk film cameras*
(MICROFILM CAMERAS) | All the advantages of 35mm slide cameras, while microfilm library techniques prevent mix-up of images. Index, file, retrieve and view with conventional 35mm microfilm equipment and techniques. |

B. 35mm MICROFILM INDEXING AND VIEWING EQUIPMENT*

C. COPY EQUIPMENT TO EXTRACT SINGLE FRAMES FROM THE 35mm MICROFILM*

D. MICRODENSITOMETER-SPECTROPHOTOMETER ANALYSIS EQUIPMENT FOR AERIAL FILM. THIS EQUIPMENT WILL WORK FOR COLOR AND COLOR INFRARED FILM*

E. OTHER HARDWARE

1. Thermal Scanners (Conventional equipment)
2. Aircraft (The 35mm bulk film camera system is designed for use from any aircraft -- belly hole or window photography)

*Primary photographic system chosen and developed for this research work (35mm bulk film photography).

most practical and economical system for obtaining, handling and analyzing remote sensing imagery for water quality.

Second aspect of the problem to be investigated was determining the correlation between remote sensed imagery and actual water quality parameters. A summary of this portion of the work is shown in Table II.

As indicated in Table II, photographic remote sensing of water pollution primarily images the solid content. Bottom effects become significant with some combinations of depth, turbidity, wave lengths and bottom characteristics. Aquatic macrophytes and algae also appear in the imagery, depending upon the depth and the wavelength being recorded. Oil and siltation likewise can be recorded. The accuracy and reliability of the correlations of solids concentrations as determined by photographic remote sensing to ground measurements is currently under investigation.

Third aspect of the problem under investigation was determining the optimum technique for monitoring specific water pollution parameters and evaluating the reliability with which this can be accomplished. Table III presents a summary of results of investigations in this area.

During the summer of 1971 a major effort was devoted to flying over four paper mills in Wisconsin under varying conditions such as would be encountered by an operational monitoring program. Simultaneous ground truth was obtained to provide a statistical correlation between the ground-determined solids concentrations and those obtained from the remote sensed imagery. The summer of 1972 was devoted to analyzing one paper mill effluent in order to establish the repeatability of ground sampling techniques and to refine field techniques employed during 1971. At the present time all data has been collected, the 1972 imagery is being processed, and the ground truth data are being indexed and filed. Future work will be directed toward analysis of this data.

Fourth aspect of the problem under investigation is determining the extent of masking due to depth of penetration, bottom effects, film development effects and angle falloff, and developing techniques to eliminate or minimize them. The effect of these factors must be understood and effective means developed to account for them before reliable water pollution monitoring can be conducted by photographic remote sensing. Table IV summarizes results to date in this area.

Initial investigation of the effects of penetration completed during the winter of 1971 produced rough tables and graphs which, when used in conjunction with conventional secchi disc readings, provided for the prediction of and corrections for the depth of penetration and associated bottom effects. These effects are wavelength dependent. Also, crude curves, which are now being refined, were prepared for the effect of angle and lens falloff.

A SUMMARY OF CORRELATION OF
WATER QUALITY PARAMETERS AND REMOTE SENSED IMAGERY

A. BACKGROUND

1. Background water itself; also air column and surface effects.
2. Background water is penetrated to some depth. Therefore, one sees a column of water.
3. In some cases BOTTOM EFFECTS from the bottom of the water body. In some cases water surface effects, as with oil.

B. AQUATIC WEEDS

1. Types are shown.
2. Maturity and vigor are shown.
3. Depth penetration effects come into play here in that penetration is wavelength dependent and there is a color shift in a weed bed depending on its depth.

C. ALGAE

1. Some types theoretically can show (greens vs. blue-greens).
2. Algae vigor is a factor.
3. Concentration shows, but one must consider the depth penetration effects as well as the bottom effects of the lake being analyzed.

D. SILTATION

1. Shows up with a distinctive color.
2. Concentration theoretically can be mapped easily by techniques being developed in the water pollution studies.
3. Depth penetration effects must be considered as well as bottom effects.

E. WATER POLLUTION

1. As is the case above, whenever one is not looking through the water at the bottom, what one sees in the water is solid matter. Conclusions on research to date indicate that the parameters that change the reflectance signatures from a column of water are solids. Work continues to determine whether dissolved, fixed, total, suspended, or volatile solids are the most significant for particular industrial outfalls.
2. Concentrations of solids theoretically can be determined from aerial images by at least two methods. The statistical accuracy and reliability is being investigated.
3. Field sampling and film analysis must take into consideration depth penetration and bottom effects.

CONCLUSIONS:

AS THERMAL IMAGERY SHOWS SURFACE TEMPERATURE OF THE WATER, AERIAL PHOTOGRAPHY CORRELATES TO SOLIDS IF PROPER CONSIDERATIONS ARE MADE FOR DEPTH PENETRATION AND BOTTOM EFFECTS.

SUMMARY OF TECHNIQUES FOR
MONITORING SPECIFIC WATER POLLUTION PARAMETERS

A. AQUATIC WEEDS

1. Type mapping Use color and color infrared film; project, rectify and match to a map, then strict interpretation and drawing in of the boundaries. Some field checking is needed. Depth penetration effects and color shifts should be understood.
2. Macrophyte production As with the above, but one might also use microdensitometer analysis.

Time sequence and the time dimension, as with remote sensing of all vegetation, is very important here.

B. WATER POLLUTION

1. A panel is necessary in the water for research work for:
 - a) sample location
 - b) reflectance standard
2. Water samples must be taken correctly:
 - a) laterally
 - b) vertically for depth penetration effects*
3. Analyzing the photographs:
 - a) Absolute Reflectance method of correlating reflectance with solids (must know film characteristics and effects of angle falloff).
 - b) Wavelength Ratio method of correlating photo with solids (must know film characteristics).

*NOTE:

Depth penetration effects were not understood until the fall of 1971, but by a lucky accident extensive water samples taken of paper mill discharges during the summer of 1971 were taken perfectly in accordance with ideal vertical sampling for depth penetration considerations. The laboratory analysis of these samples (solids) is being compared to the photographic images to arrive at a statistical correlation of solids in the water and the aerial photography. Determining the statistical accuracy of this correlation is one of the goals of the work for 1972-73.

C. SILTATION

The same techniques being developed for water pollution analysis can be applied to siltation.

D. ALGAE

Same as with siltation, except consideration must be given to algae type and vigor.

E. OIL AND SURFACE EFFECTS

This area is being investigated. Good initial results have been obtained so far with correlation of oil thickness with reflectance.

*Depth Penetration Effects are important in water sampling. Vertical water sampling is necessary.

TABLE IV
SUMMARY OF ANGLE FALLOFF,
DEPTH OF PENETRATION AND BOTTOM EFFECTS

A. ANGLE FALLOFF*

1. Part due to the camera lens (minor).
2. Part due to the angle of incidence to the water (major).
3. Part due to the greater path length of light through air.

B. DEPTH PENETRATION EFFECTS

1. 2 ft. or less in some waters.
2. Up to 30 ft. or more in some clear waters.
3. Can predict and calculate with SECCHI DISC readings and curves which have been roughly derived. Refinement needed on the curves.**

C. BOTTOM EFFECTS

From the curves mentioned above the effects of the bottom can be predicted. Sample data from the curves are as follows:

If the bottom is half as deep as the secchi disc reading, then the bottom effects can be as high as 10% of the total energy reaching the camera and, therefore, the film. If the bottom is equal to the secchi disc reading, then the bottom effects may be as high as 1%. If the depth to the bottom is twice the reading, then the bottom effects are less than 0.1%, etc.

NOTE: WITH THE SECCHI DISC READING IN THE WATER AND THE CURVES, ONE CAN PREDICT NOT ONLY THE DEPTH PENETRATION EFFECTS AND CORRECT VERTICAL SAMPLING, BUT ALSO THE BOTTOM EFFECTS.

* Some rough curves and suggested methods of handling the angle effects are given in the Chicago Report mentioned below. The curves, however, need refinement and work is planned for this refinement.

** The curves for depth penetration were first published in "The Final Report on Infrared Photography Applied Research Program in Conjunction with the Metropolitan Sanitary District of Greater Chicago," J.P. Scherz, 1971. This project was funded by Chicago, which gave permission for the University to use the results.

Results of this work are being incorporated into the analysis of field data acquired during the summer of 1972.

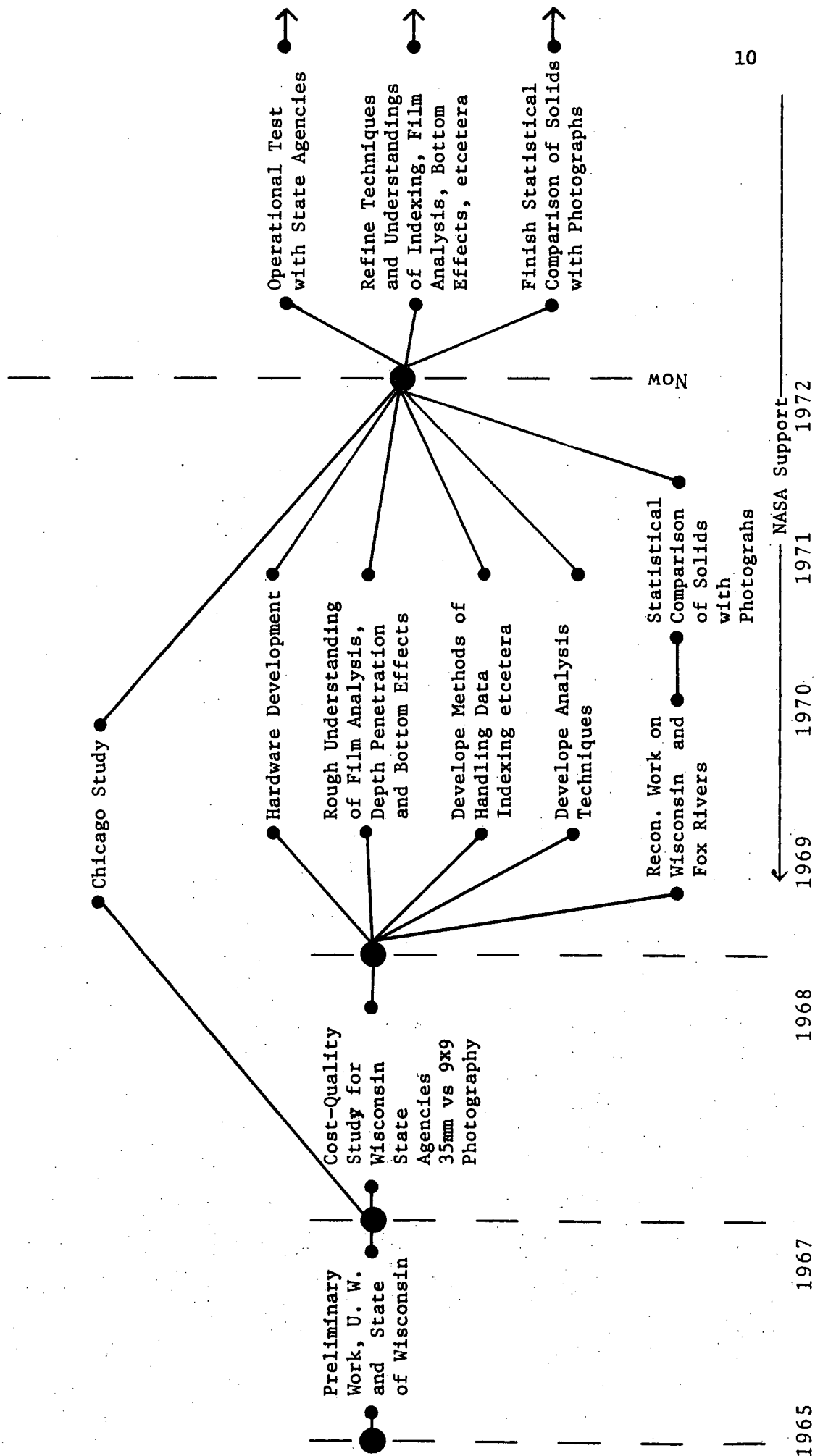
Final aspect of the problem is developing operational procedures which might be employed by a municipal, state or federal agency for the application of remote sensing to water quality monitoring. This may well prove to be the most difficult of the five fundamental areas under investigation. Inasmuch as the first four fundamental aspects of the problem are at least basically understood, steps were taken during the past year to develop working relationships with operational agencies to test the effectiveness of airborne remote sensing in water quality monitoring. Working contact has been established and initial reconnaissance work conducted with three operational agencies, namely: 1) Wisconsin Department of Natural Resources, 2) Wisconsin Department of Transportation, and 3) U.S. Army Corps of Engineers. Figure I indicates in diagrammatic form the relationship of the past work on the application of remote sensing to water quality monitoring and its projection into the final phase.

B. FUTURE WORK

During the 1972-73 period the imagery and ground truth from the past summer's field work will be analyzed for reliability and statistical correlation of water solids parameters and concentrations with image density. Depth of penetration, bottom effects, and angle effects also will be appropriately considered and eliminated as required. Planning in progress with the Wisconsin Department of Natural Resources will continue for implementing the use of photographic remote sensing in the monitoring of paper mill and treatment plant discharges. Similar planning is in progress for testing the application of such data in environmental impact studies with the Wisconsin Department of Transportation and the U.S. Army Corps of Engineers. These programs should be ready for implementation at the time the statistical analysis of the correlations is completed.

FIGURE 1

Relationship of Past and Present Work on the Application of Remote Sensing to Water Quality Monitoring



III. APPLICATION OF REMOTE SENSING TO SURFACE PARAMETERS OF LARGE WATER BODIES

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Research Associate:

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Project Associate:

Frank L. Scarpace, Remote Sensing Program and Marine Studies
Center

ABSTRACT

Airborne infrared radiometric techniques including imaging are being used to investigate nearshore circulation patterns in the Great Lakes with special emphasis on thermal plumes of nuclear and fossil fuel power plants. Interaction of the plumes with longshore currents, the speed and stability of longshore currents, and nature of the mixing between coastal and central lake water also are being studied. These phenomena change significantly with the seasons.

Detailed measurements of water movement in thermal plumes and other coastal circulation features are being made by aerial photography of lines of floating markers. This technique, combined with infrared radiometry, provides synoptic information on the surface thermal and motion field obtainable by the conventional surface ship approach.

INTRODUCTION

Concern has been expressed by many environmentally oriented groups for the loss of water quality and lack of pollution control in the Great Lakes. For these practical as well as for scientific reasons, it is important to gain an understanding of the general circulations and mixing processes of the Great Lakes. Both long and short range effects of dumping wastes into the lakes are related to their general circulations. A detailed knowledge of where and how pollutants introduced along the shore mix with central lake water is necessary before intelligent regulations or recommendations for changes can be made.

Lake pollutants are almost always introduced at the shoreline.

The rate at which these pollutants become significantly diluted is determined by the mixing rate of nearshore water with off-shore water. Thus, measurements of this mixing and an understanding of the underlying physical mechanisms are needed to predict nearshore concentrations of pollutants.

Goals of this research are an understanding of the mechanisms which strongly affect the rate of mixing of nearshore and off-shore water in Lakes Michigan and Superior. To this end, the investigators are studying the narrow, intense Keweenaw current flowing eastward along the northern coast of the Keweenaw Peninsula in Lake Superior, and the surface temperature structure near the power plants on the western coastal zone of Lake Michigan. These typify the mixing processes associated with "point" and "distributed" sources of pollutants.

PROJECT OBJECTIVES

(1) To measure surface velocity structure using aerial photography and analytical photogrammetry on Lake Superior and in the thermal plumes of Lake Michigan.

(2) To use remote sensing techniques to study nearshore surface temperature structures of Lakes Superior and Michigan.

(3) To correlate the direct current measurements with those inferred from radiometric surface temperature measurements.

(4) To calculate, in all cases, mixing rates between nearshore and offshore waters.

PROJECT RESULTS

A. Lake Superior

Several experiments were conducted during the summer 1971 to determine the detailed structure of the Keweenaw current by photogrammetric means. Although preliminary in nature, they were quite successful.

An area one mile wide and extending seven miles north of Eagle Harbor, Michigan (see Figure 1), was selected for study because of the proximity of the current to shore as revealed from aerial temperature surveys (Ragotzkie, 1966). Since the operation was conducted in a region removed from ground orientation, a network of up to eleven moored buoys was established at approximately one-mile intervals throughout the area. Masts and flags were installed on each buoy to permit visual observations from two shore-based theodolite stations.

The basic procedure consisted of the continuous distribution of 28-inch by 44-inch white posterboards in lines and circles from two research vessels along the upstream line of buoys. After seeding had commenced, aerial photographs were obtained with

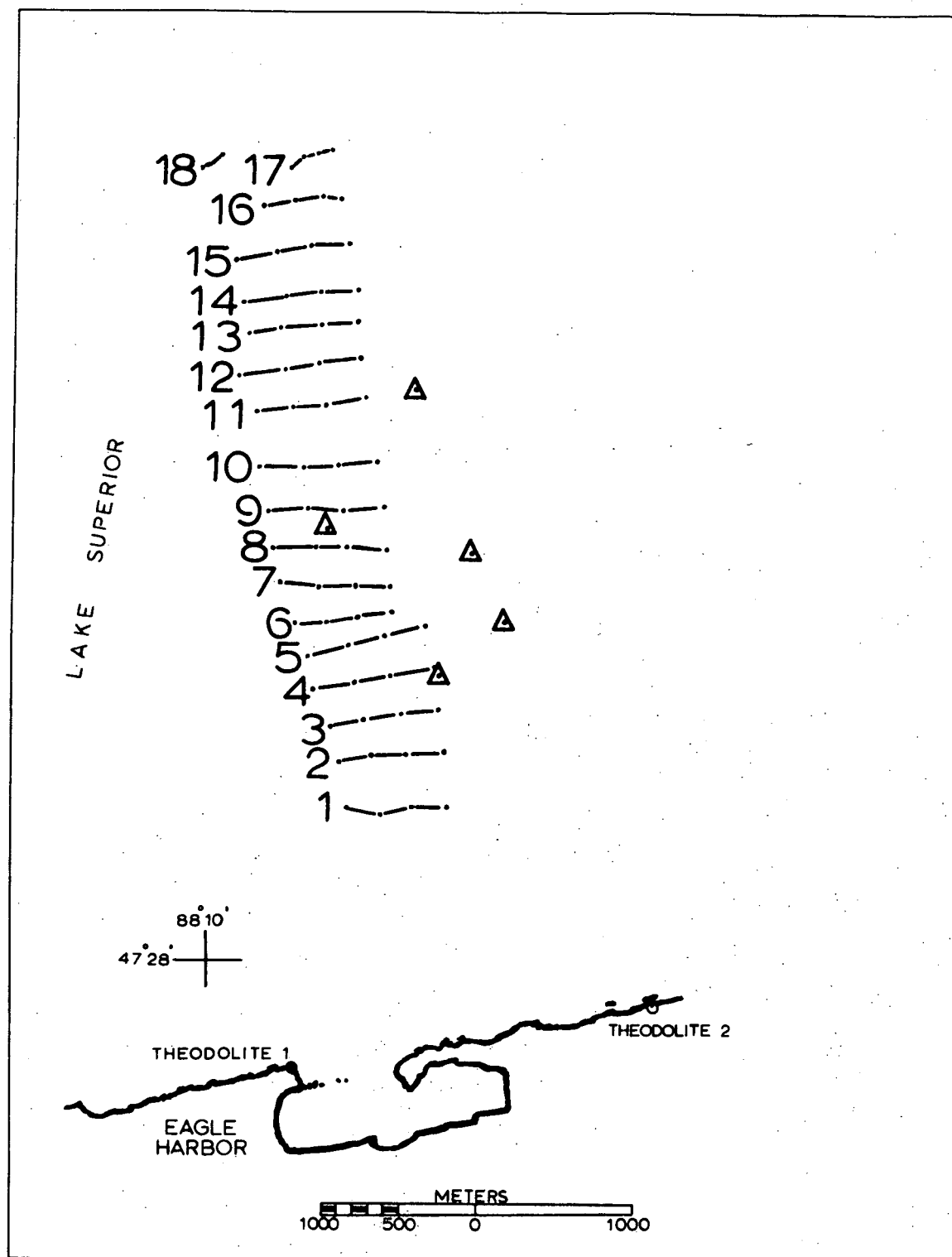


FIGURE 1

a calibrated F-56 camera at a scale of 1:14,000 using 70 percent endlap over flight lines coincident with buoy lines. One flight line consisted of 20 to 25 photographs. The interval between photographic passes varied from eight to ten minutes, with flight durations extending to three hours. Throughout the operation, continuous monitoring of the buoy and boat positions was achieved from both theodolite shore stations. The boats were also used to track drogues and to obtain BT and Whitney temperature measurements. Nearly 100 flights were made over the survey area, with most of the 2,000 photographs obtained under lake conditions of flat calm and zero wind speeds. More than 2,500 drift cards were used, and approximately 15,000 current vectors can be derived from the photographs (Table 1).

Six aircraft passes were selected for initial analysis, four from August and two from September, based upon the number of control buoys present and weather conditions of flat calm and zero wind speeds. The photogrammetric positions of one drift card row for the time period 1717 to 1741 on 4 August 1971 are shown in Figure 1. Individual drift card velocities for the resulting current vectors are listed in Table 2. Speed profiles for the 74 common drift cards and 155 velocities are plotted in Figure 2. The composite surface current structure is depicted in Figure 3. These results indicate a longshore current speed of about 50 cm/sec extending to a distance of 5- $\frac{1}{2}$ kilometers from shore, where the speeds rapidly decrease to 15 cm/sec (not shown in Figure 2). These varying speeds suggest complexities in the surface current structure (Figure 3). Of interest is the area of relatively low speeds three kilometers offshore. This region is consistent for all time intervals involved and coincides with the convergence suggested by drift cards five to seven in Figure 1. At least two regions of relatively higher flow are evident in Figure 2. These are similar to the diverse bands of currents in Lake Ontario reported by Csanady (1972).

The temperature structure on 4 August 1971 was obtained with a Whitney Underwater Resistance Thermometer (Figure 4). Associated dynamic height currents, computed by the method of Ayers, are shown in Figure 5. The calculated surface velocity profile agrees remarkably well with the photogrammetrically derived structure in both magnitude and spatial distribution, including the region of low velocity at three kilometers and the sharp velocity gradient at six kilometers. These results indicate that the baroclinic flow component is dominant.

The BT temperature structure and dynamic height current for 6 August are also shown for comparison (Figures 6 and 7). Although a two-day interval exists, the profiles are quite similar to those on 4 August.

The photogrammetric velocity profile between aircraft passes 3 and 8 at times 0849 and 0943 on 9 September are shown in Figure 8, with the geographical positions of one row of cards depicted in Figure 9. The 224 velocities vary in direction from 070°T to 108°T. Speed fluctuations are similar to those in

TABLE 1

DATES AND DURATION OF EXPERIMENTS
WITH NUMBER OF PHOTOGRAPHS OBTAINED

Date	<u>Duration (Hours)</u>		Photographs
	A.M.	P.M.	
3 August 1971	1 ½	1 ½	400
4 August 1971		3	340
5 August 1971		3	260
6 September 1971		1 ½	200
7 September 1971		3	375
9 September 1971	2	2	425

TABLE 2
 COMPARISON OF PHOTOGRAMMETRICALLY DERIVED
 DRIFT CARD DIRECTIONS ($^{\circ}$ T) AND SPEEDS (cm/sec)
 FOR ROW B ON 4 AUGUST 1971

Drift Card Number	Time Interval					
	1717-1725		1725-1733		1733-1741	
	Direction	Speed	Direction	Speed	Direction	Speed
1	093	47	086	44	095	45
2	085	48	086	48	089	48
3	080	48	081	49	085	49
4	082	51	081	51	082	51
5	079	52	078	51	079	51
6	090	44	082	43	085	42
7	095	47	092	48	094	48
8	094	50	092	46	094	49
9	099	48	095	51	090	49
10	089	51	090	50	087	49
11	083	46	087	48	083	49
12	081	45	084	47	087	51
13	080	43	088	51	084	50
14	086	48	086	50	086	52
15	079	46	083	49	084	52
16	-	-	079	41	086	40
17	-	-	074	21	078	18
18	-	-	049	17	070	16

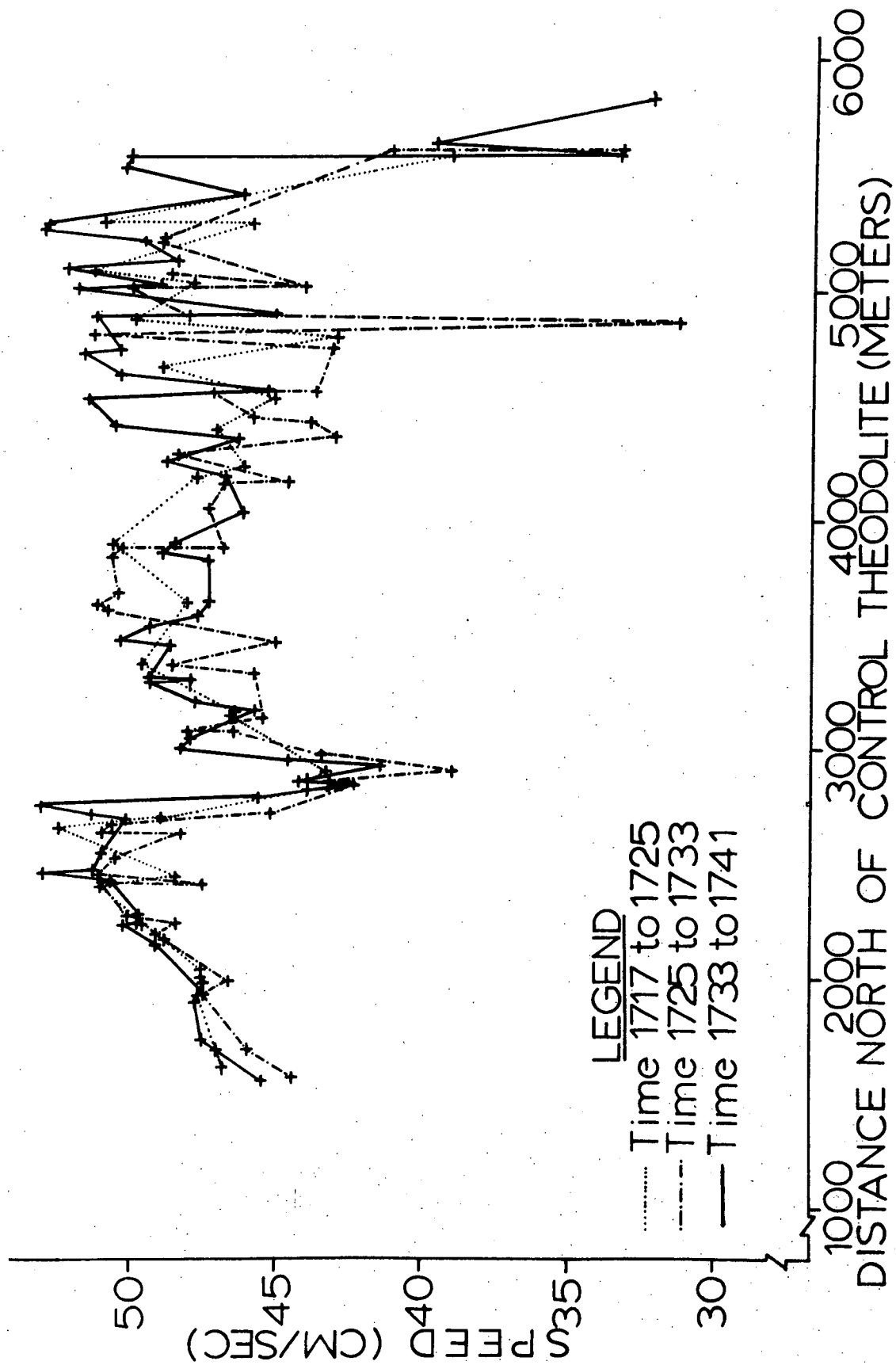


FIGURE 2

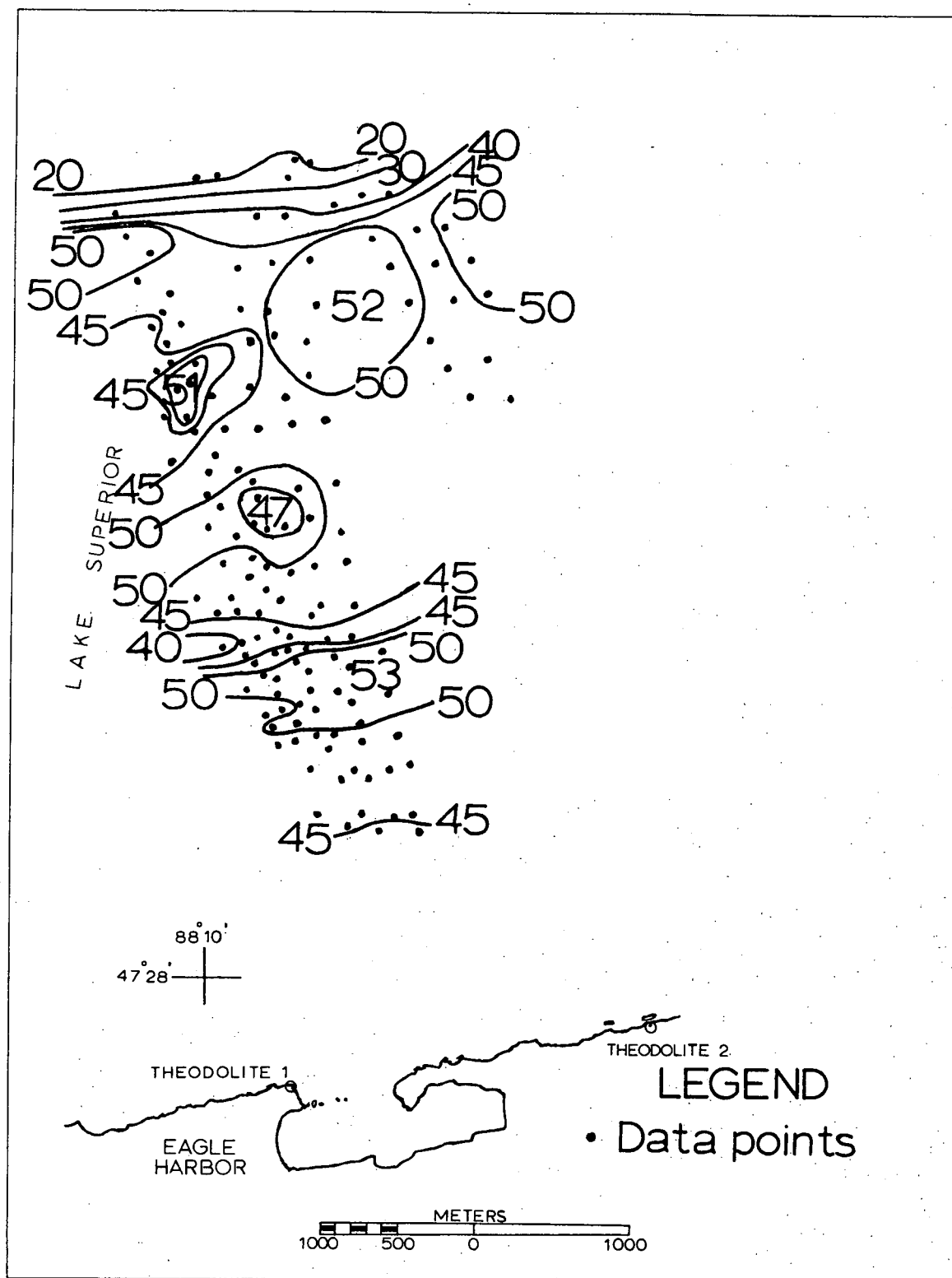


FIGURE 3

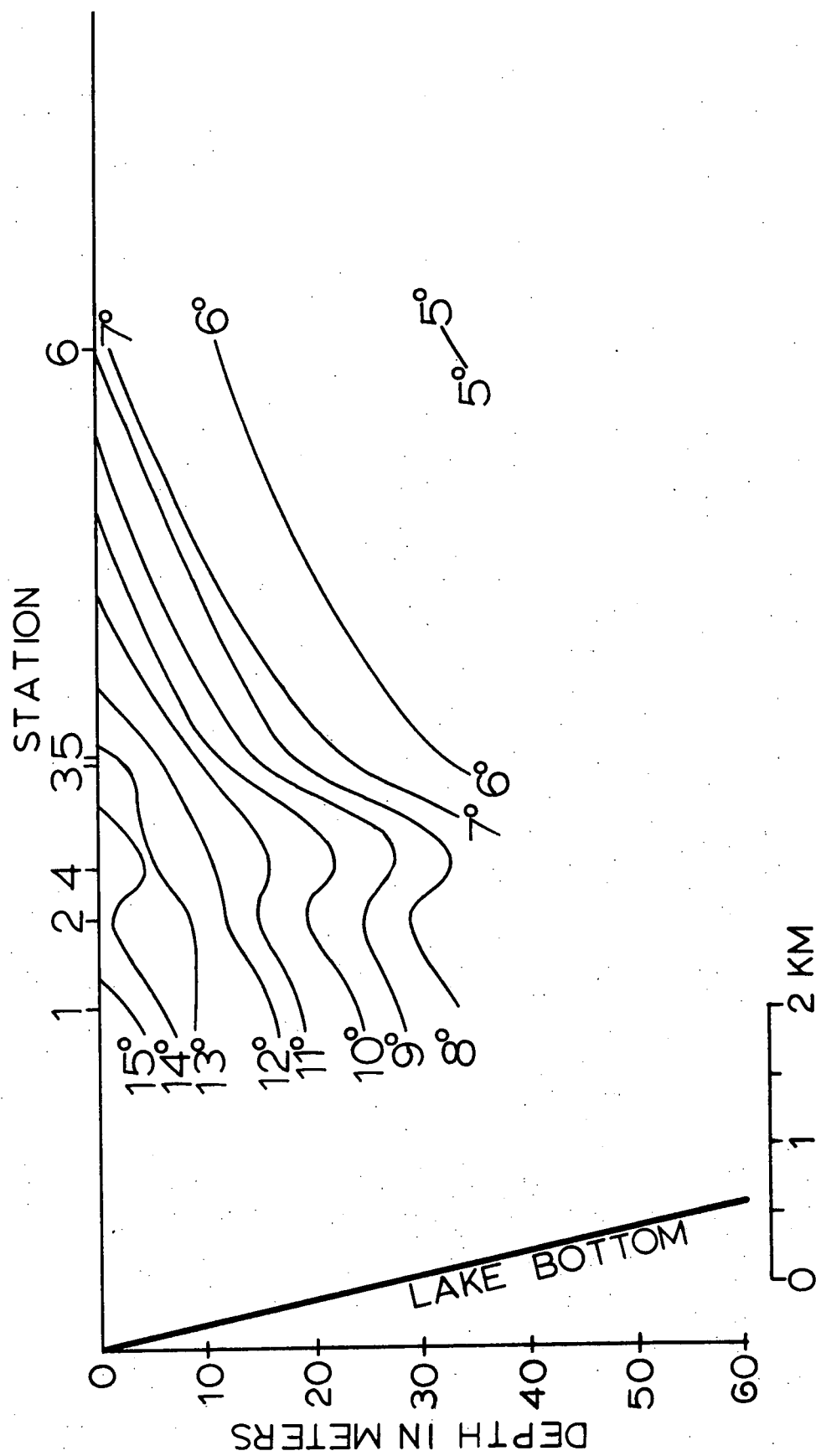


FIGURE 4

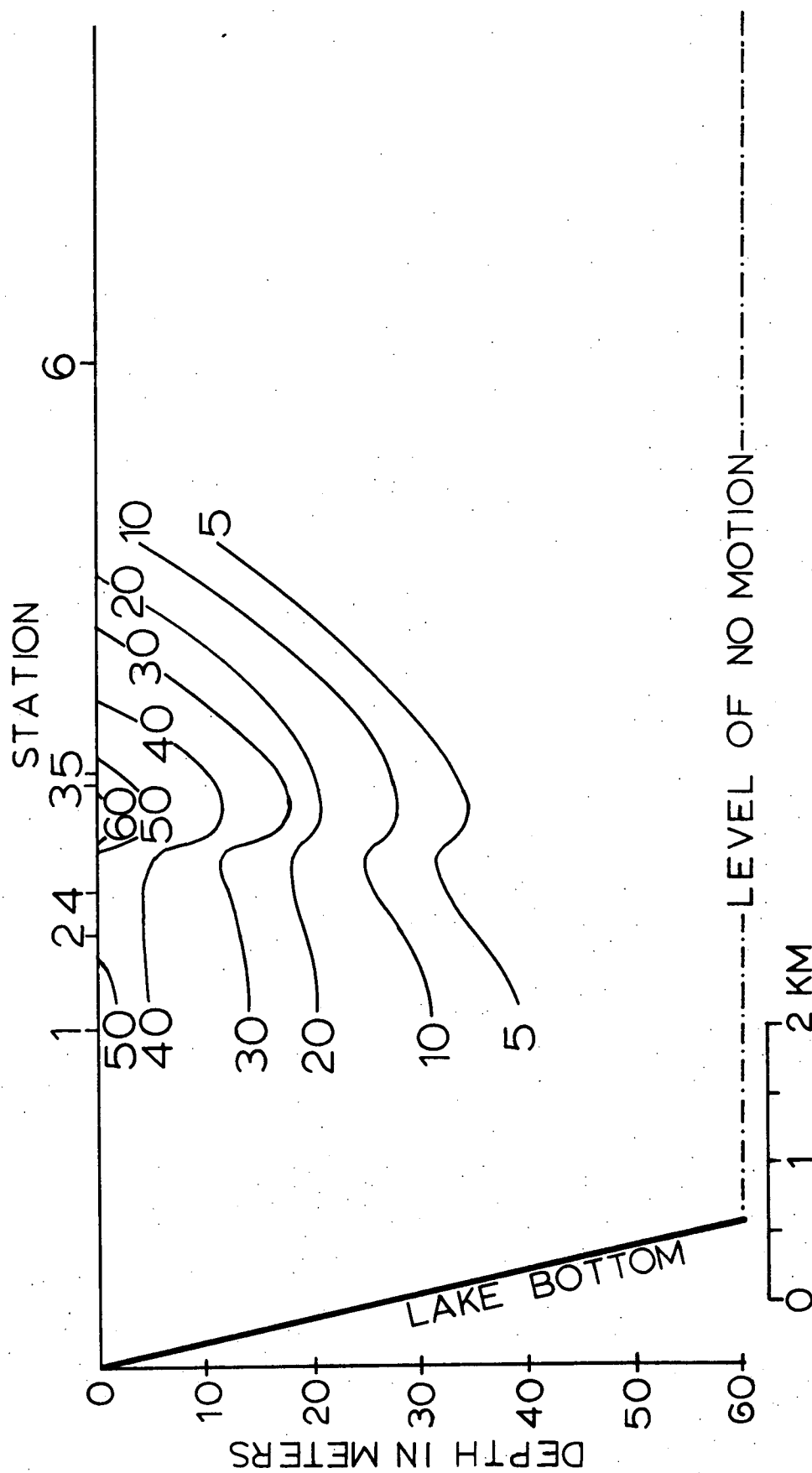


FIGURE 5

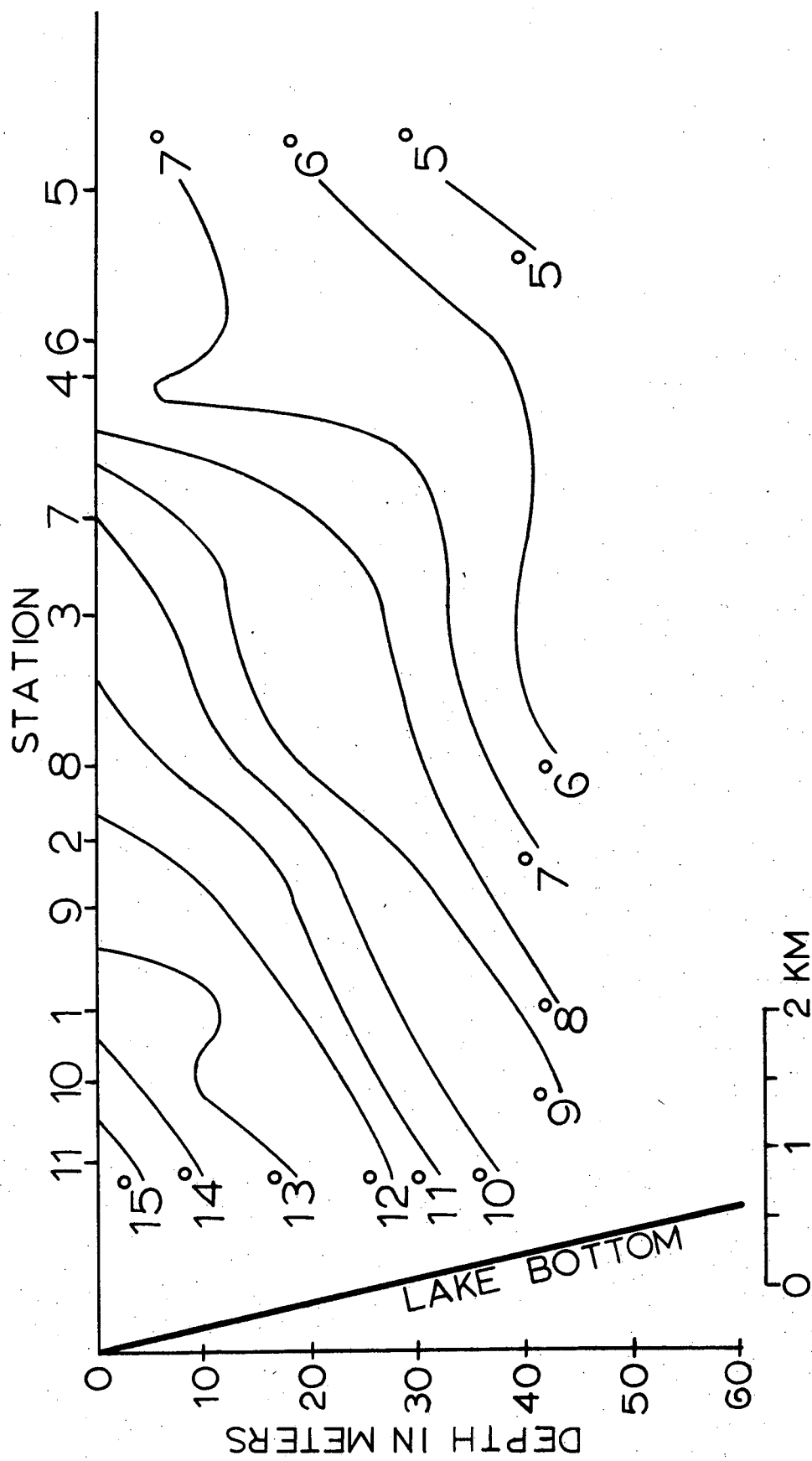


FIGURE 6

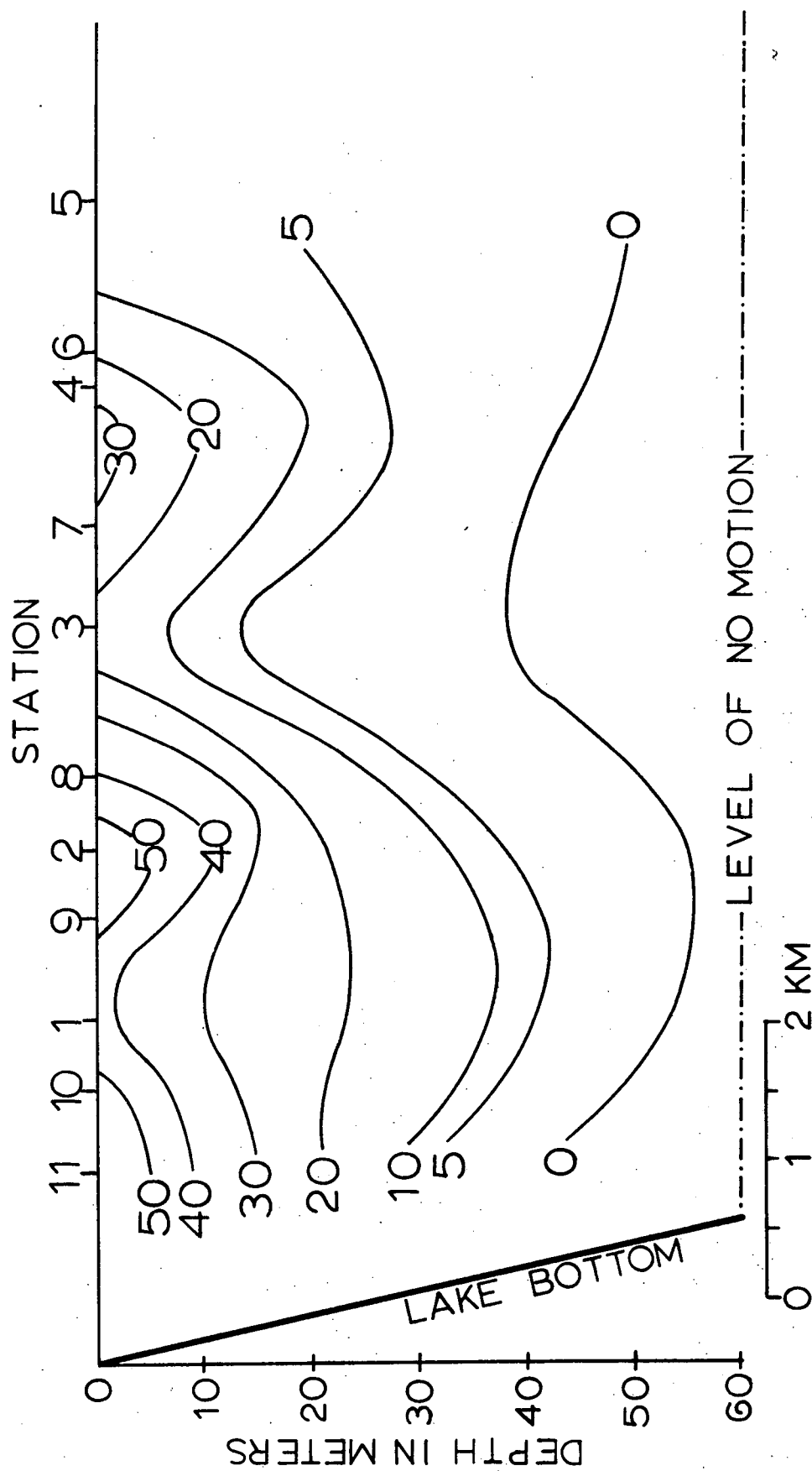


FIGURE 7

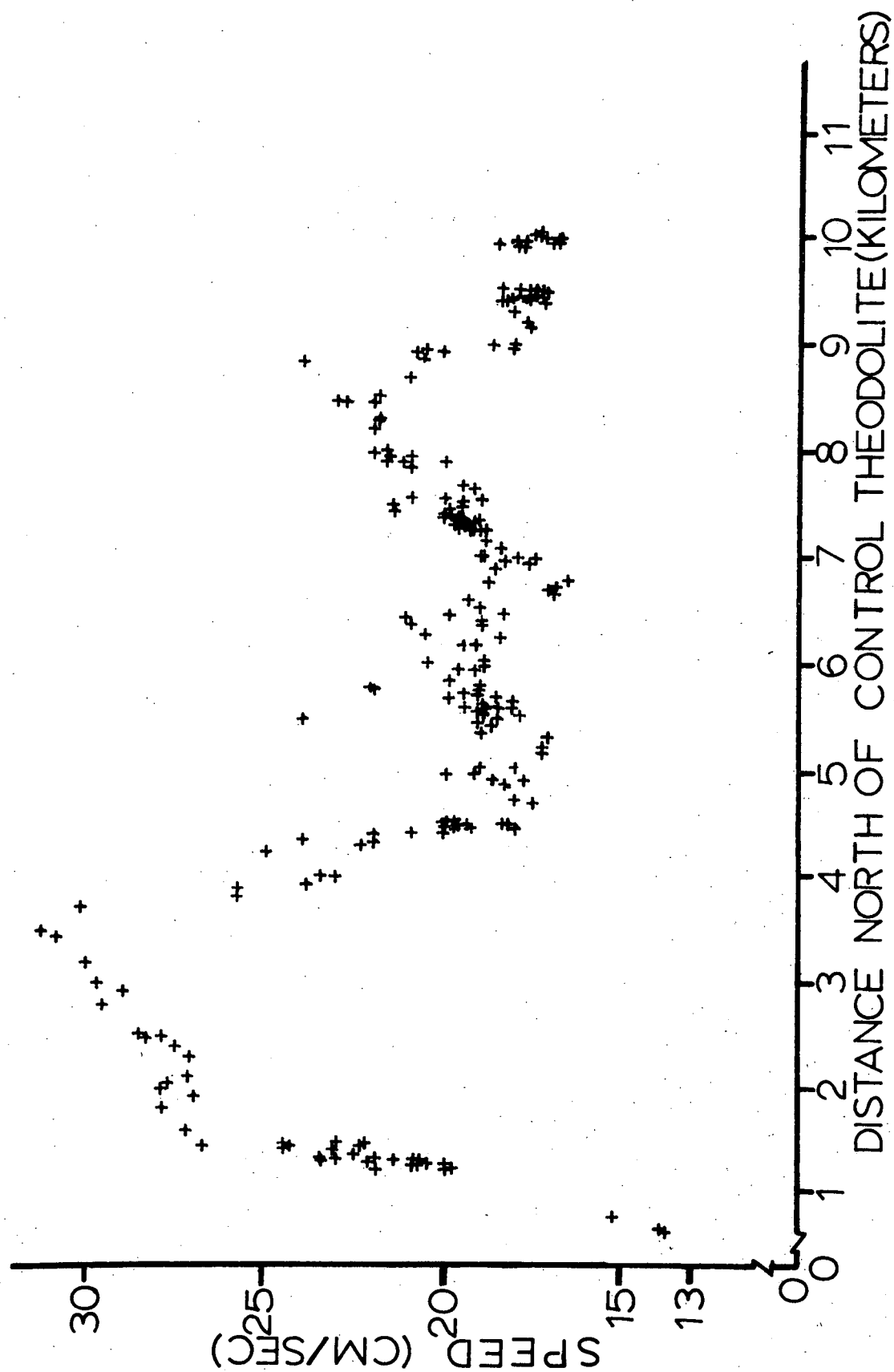


FIGURE 8

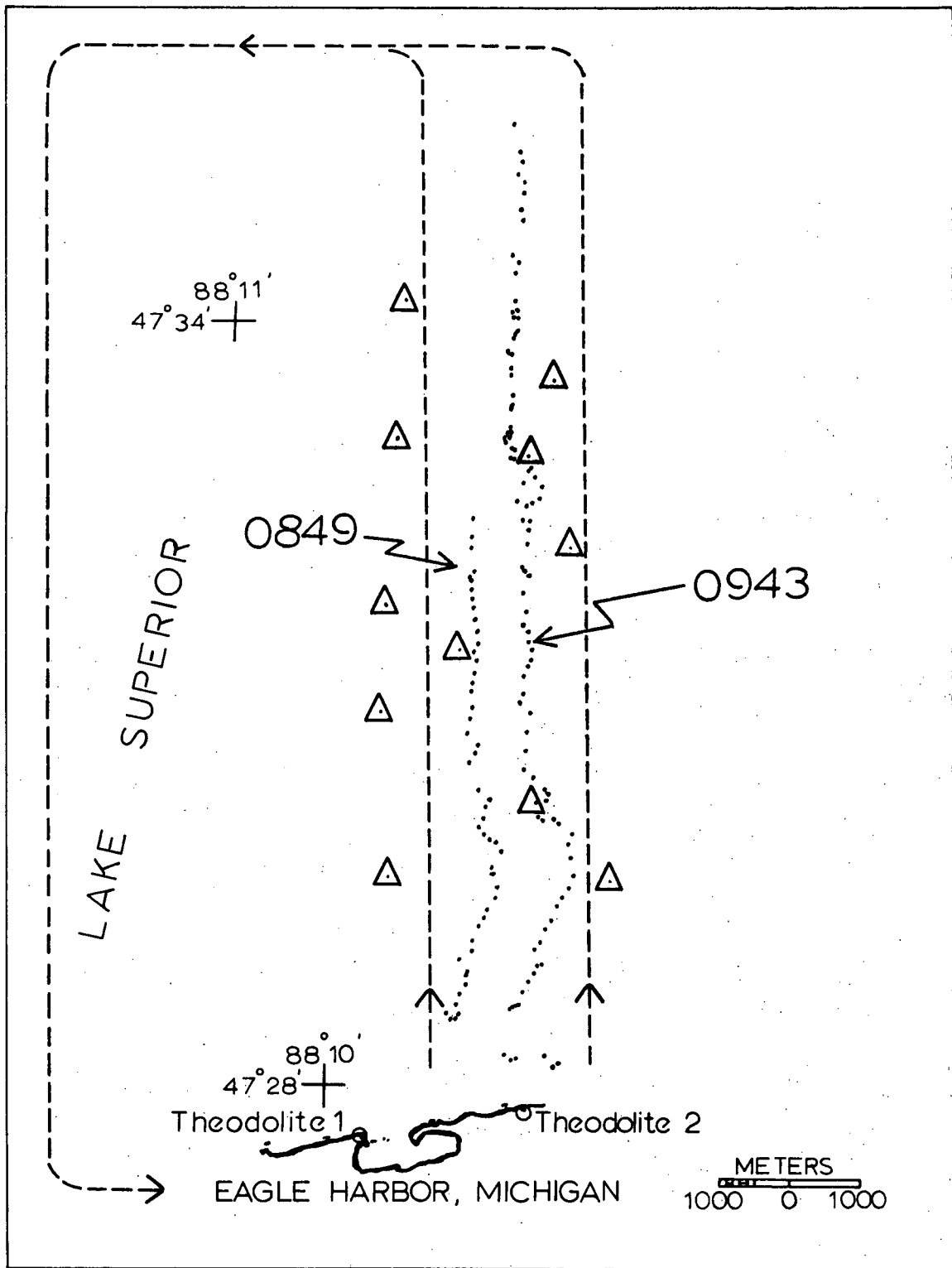


FIGURE 9

August (Figure 2). Current speeds were significantly less than those encountered in August. In addition, the current width is more than ten kilometers. A pronounced region of relatively higher velocity extends from one to four kilometers offshore.

Operations precluded temperature measurements on 9 September. For comparison, the temperature structure and computed currents for 6 September 1971, three days earlier, are shown in Figures 10 and 11. Due to the time interval involved, no definite conclusions can be made concerning the correspondence between observed and calculated velocities other than a very rough agreement in current extent. Computed speeds greatly reduced baroclinic contribution to the total flow. It is interesting to note that the countercurrent (Figure 11) was observed from drift card monitoring aboard the research vessel, at this location, on 7 September.

A rough comparison between photogrammetric velocities and those determined by theodolite tracking was possible during the time interval from 0922 to 0940 on 9 September. The 40-foot research boat, while serving as an additional photo control point, was adrift nine kilometers from the control theodolite. Bearings obtained each minute indicated an average speed of 23.3 cm/sec in the direction of 092°T. The photogrammetric velocity for drift card A45, within 100 meters of the boat, was 21.4 cm/sec at 076°T. Separation between the boat and card A45 and the shorter time period involved probably account for this discrepancy, large by photogrammetric standards.

Preliminary results from this investigation indicate that accurate, nearly synoptic current information can be obtained across an entire coastal region, removed from ground orientation, by using aerial photography and photogrammetric reduction methods. This procedure, a combination of individual techniques commonly employed in photogrammetry, has not been applied previously, to our knowledge, to any extensive study of coastal currents. While the photogrammetric results compare very favorably when direct comparisons can be made using drogues and geostrophic calculations, further comparisons are necessary and will be made as more data are reduced.

Surface velocity structure observations off Eagle Harbor reveal a pattern of multiple currents confined close to shore. Although the general spatial distribution is repeatable, velocity fluctuations greater than ten percent occur at approximately fixed points in space. The nearly identical surface velocity structures on 4 August, calculated from dynamic height and photogrammetric methods (the only direct comparison obtainable from the derived information at present), suggest that the baroclinic flow component may play a more important role in this case than in those studied by Smith and Ragotzkie (1970) and Csanady (1972).

Results of last year's work were reported at the IAGLR Great Lakes Research Conference in April 1972, and a paper has been submitted to the Journal of Physical Oceanography.

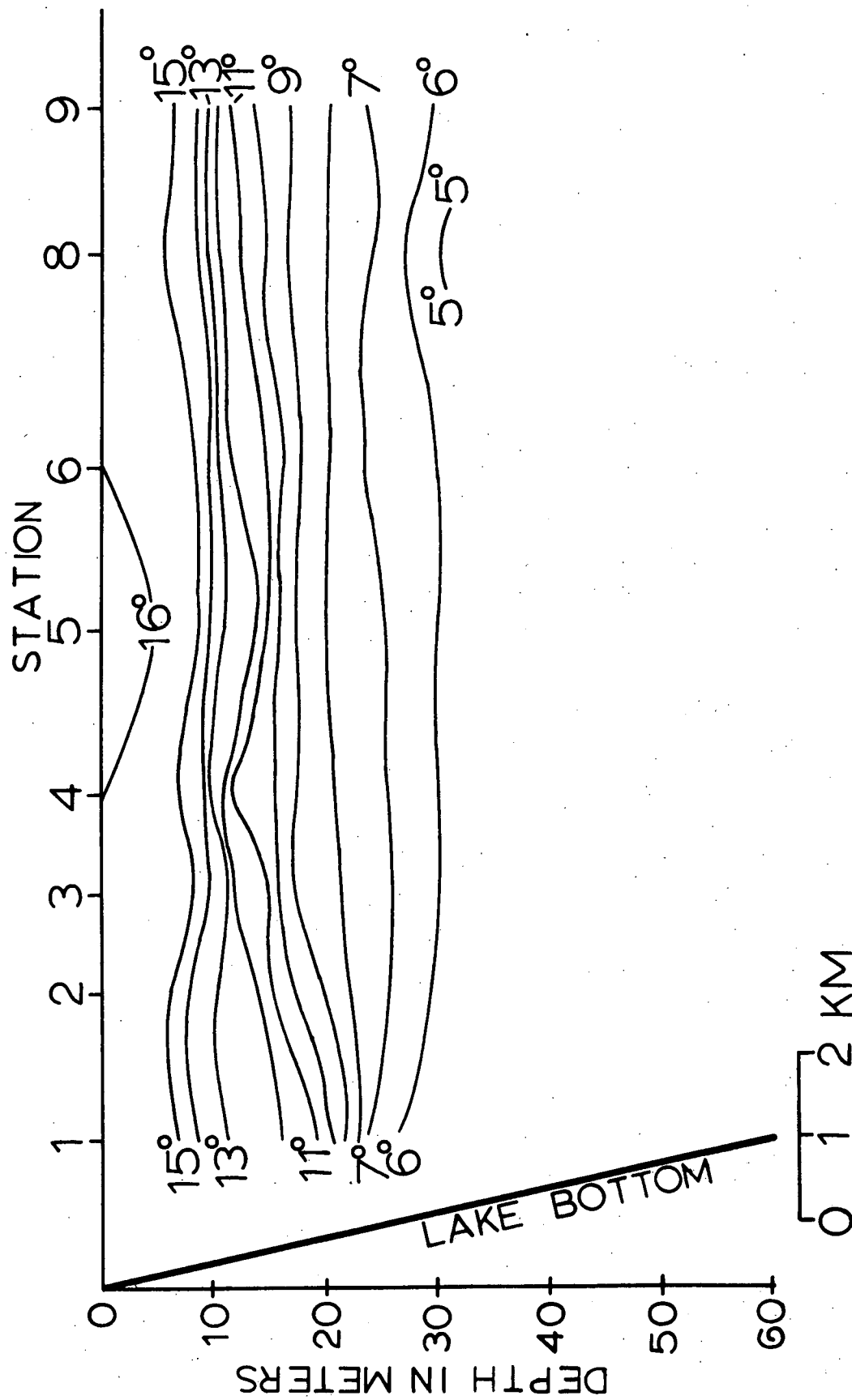


FIGURE 10

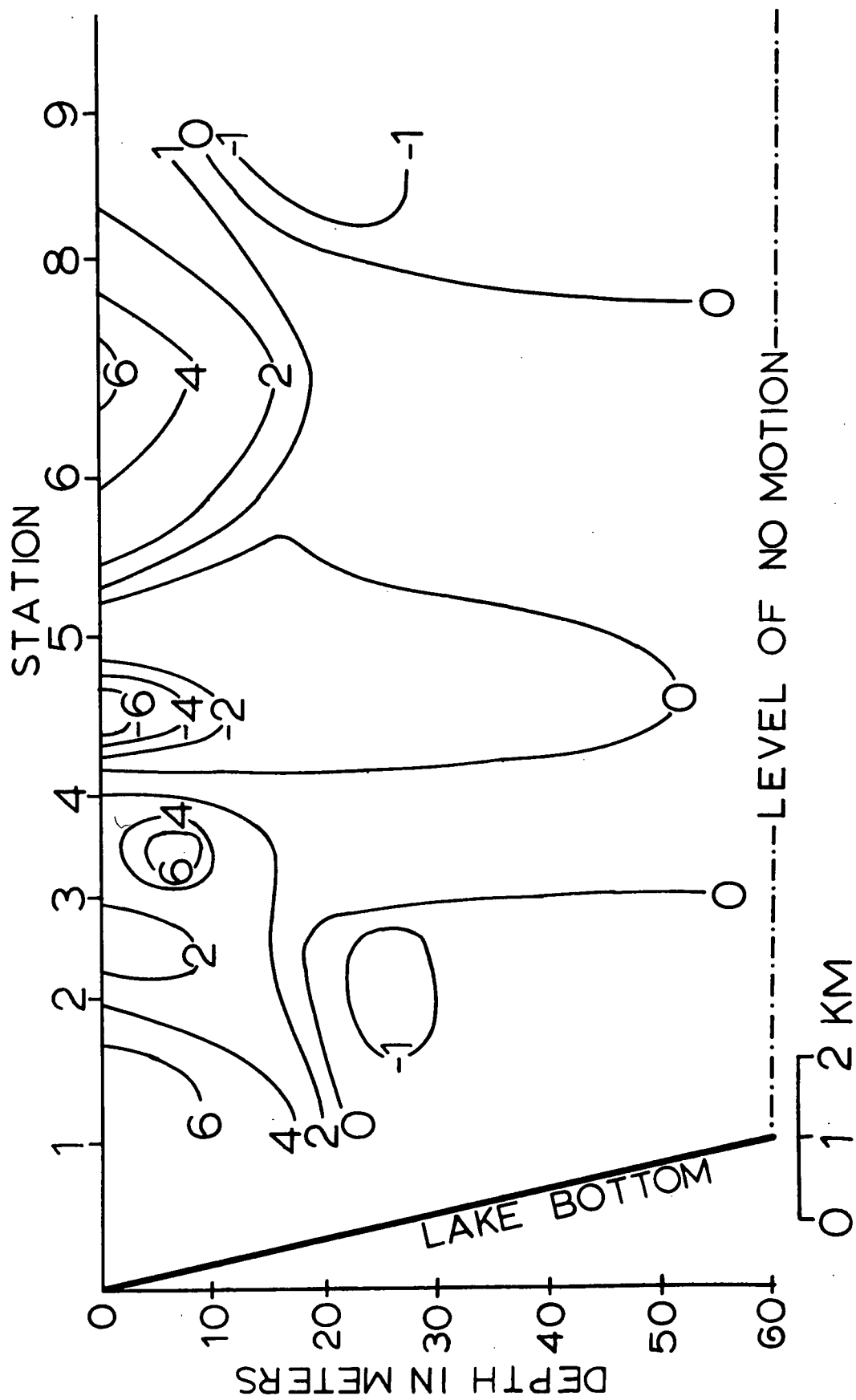


FIGURE 11

B. Lake Michigan

Emphasis in Lake Michigan was on the collective radiometric surface temperature data of the Point Beach thermal plume. Several thermal scanning overflights of the Point Beach Power Plant were conducted in the summer of 1971 and spring of 1972. Our main thrust was in obtaining accurate, reliable temperatures from the scanner data, and using these numbers to understand the behavior of thermal plumes.

An airborne Texas Instruments thermal scanner was used on four days in September 1971 to obtain synoptic measurements of surface temperatures in the plume. Each day the plane made about 15 passes over the plume at five-minute intervals. Ground truth was provided by the University of Wisconsin R/V Aquarius and smaller craft, using a Barnes PRT-5 radiation thermometer (to find temperatures beneath the surface). Simultaneous color and color-infrared aerial photographs were also obtained. Pictures of drogues set in the plume provided some (but not much information on velocity structure.

A typical sequence of thermal images is shown in Figure 12. The most interesting feature of these images is the series of concentric thermal fronts spreading radially outward from the outfall, across which the surface temperature changes abruptly by around 2°C . Their motion can be followed easily in the successive images; an example is shown in Figure 13. The fronts can also be seen, though not so clearly, in the color and color IR photographs.

The scanner film was analyzed with an Optronics, Inc., densitometer. By using the surface radiation thermometer data, absolute temperature accuracies of $\pm 0.2^{\circ}\text{C}$ were possible. Temperature variations were more accurate. The spatial resolution element was about seven feet.

Temperature and temperature gradient fields were calculated from the densitized data. The temperature fields show little more than is obvious from the raw data shown in Figure 12. The absolute gradient field is more interesting; an example is given in Figure 14. Details of the gradients in a typical thermal front are shown in Figure 15.

Because temperature gradients are biologically important, a measure of the plume surface area covered by absolute horizontal gradients of various strengths is of interest. Two such histograms are shown in Figure 16. They are compared to one based on the usual theoretical assumption that the surface temperature has a Gaussian distribution normal to the plume centerline, and the usual theoretical result that it decreases with the inverse square root of distance along the centerline. (see, for example, Hoopes *et al.*, 1968). More recent models, such as that of Koh (1970), predict centerline temperature variations that differ from this, but not markedly so. The width of this model plume was taken from several isoline charts plotted

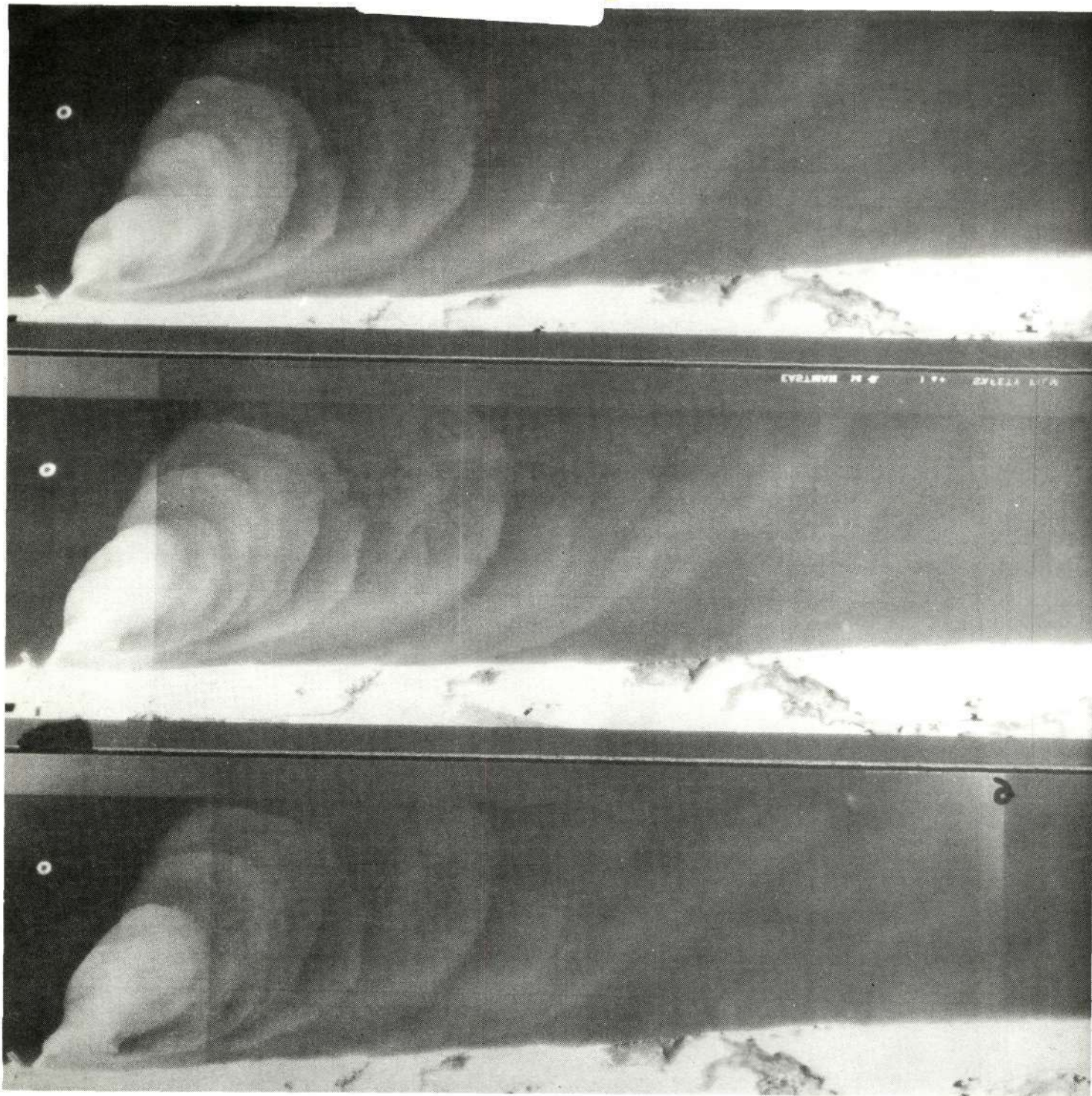


FIGURE 12 Thermal imagery of the Point Béach thermal plume (September 1971).
The pictures were taken about five minutes apart.

SURFACE VELOCITY STRUCTURE ASSOCIATED
WITH THERMAL FRONTS

DISTANCE: 300 FT.

VELOCITY: 60 FT./MIN

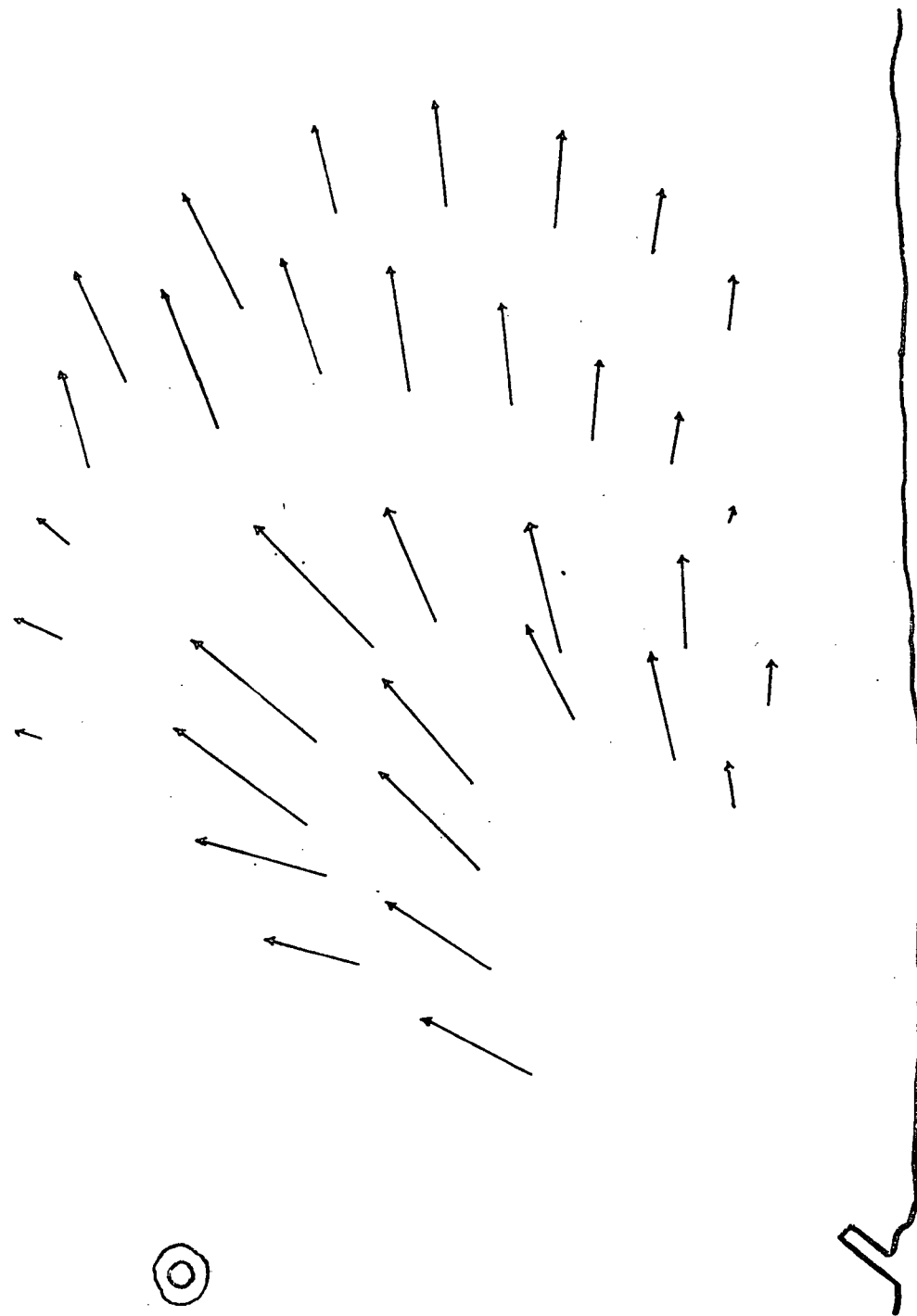
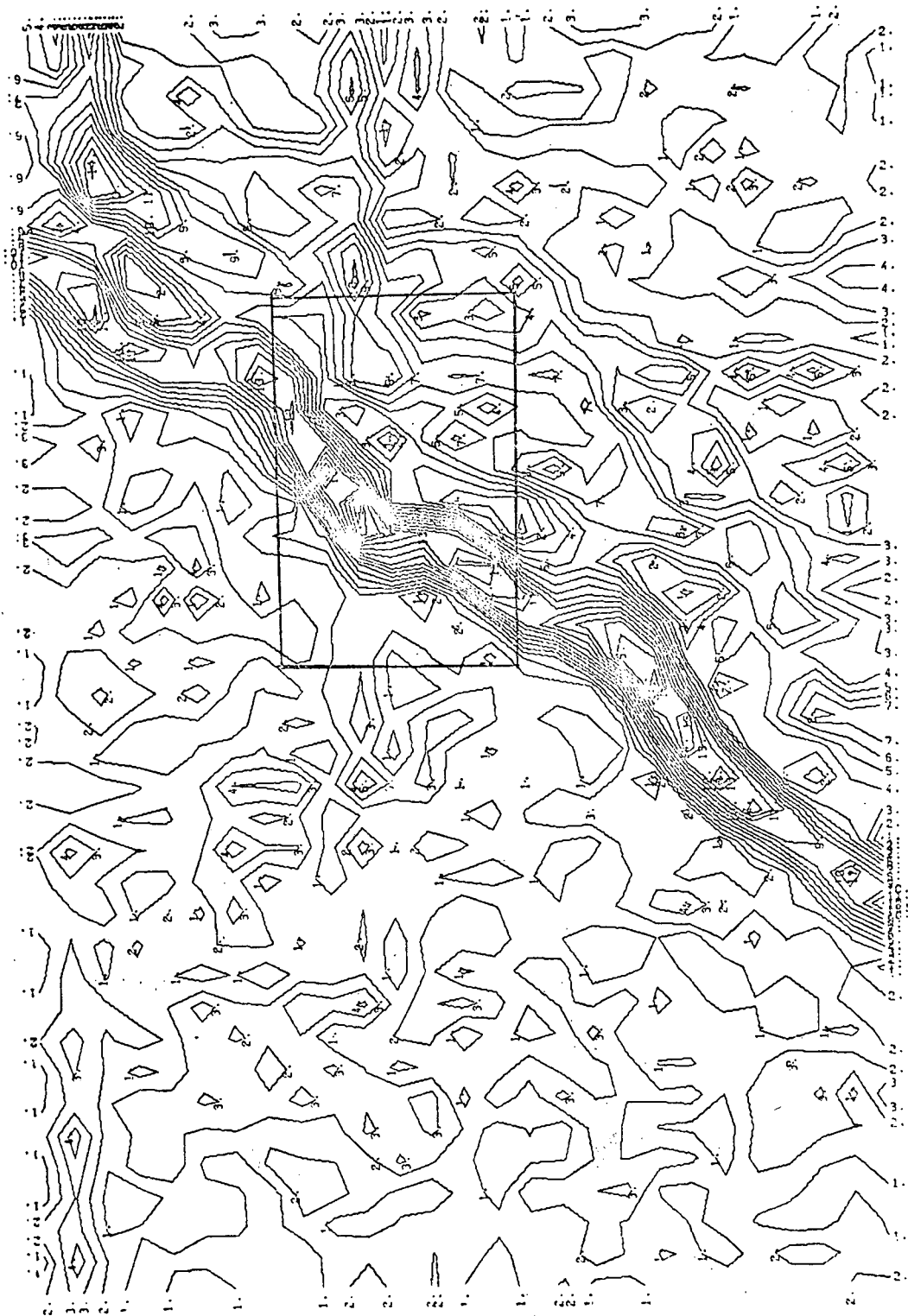


FIGURE 13

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CONTOUR OF GRADIENT IN DEGREES PER FOOT TIMES 140



Y AXIS

X AXIS

FIGURE 14

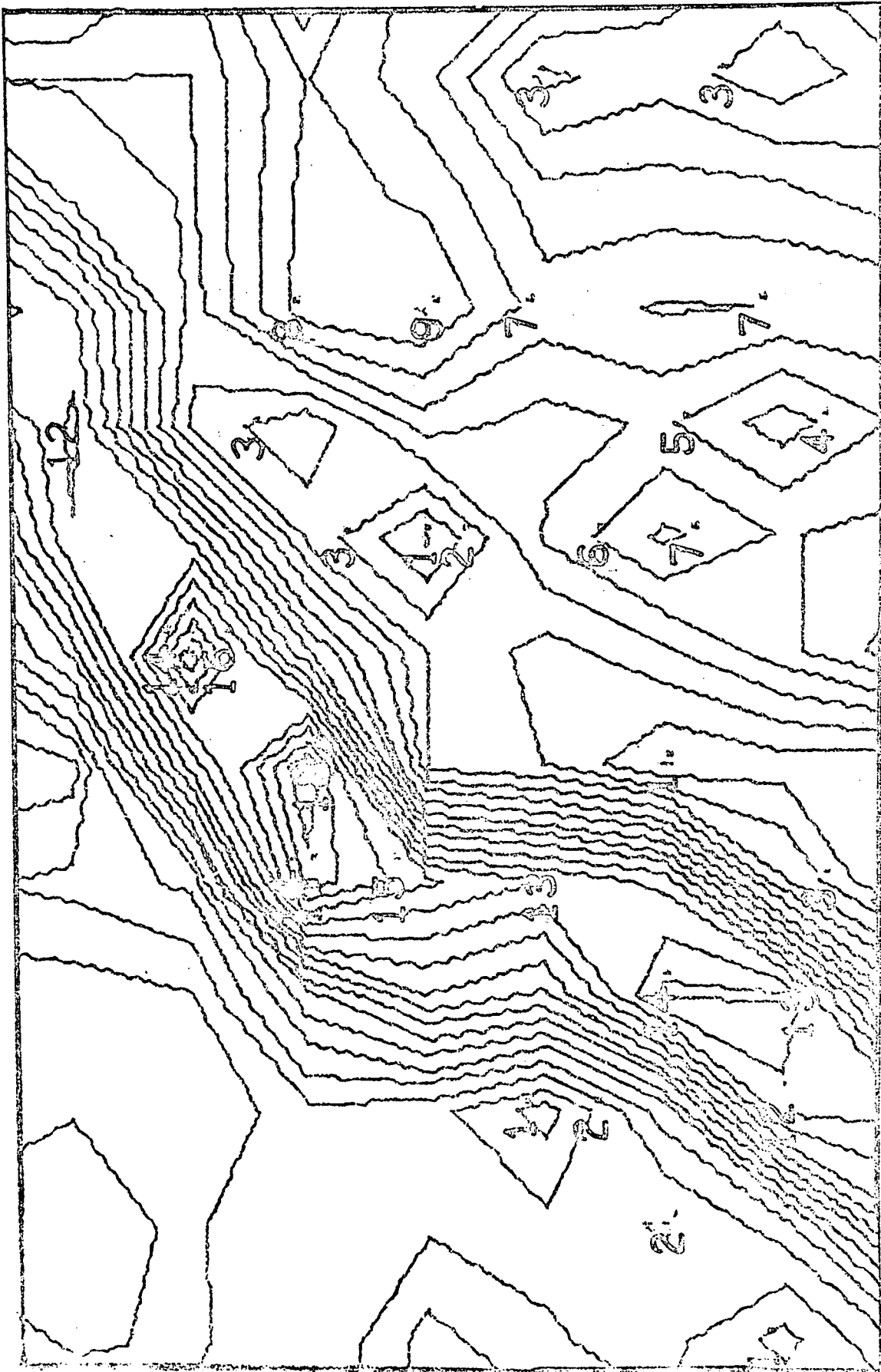
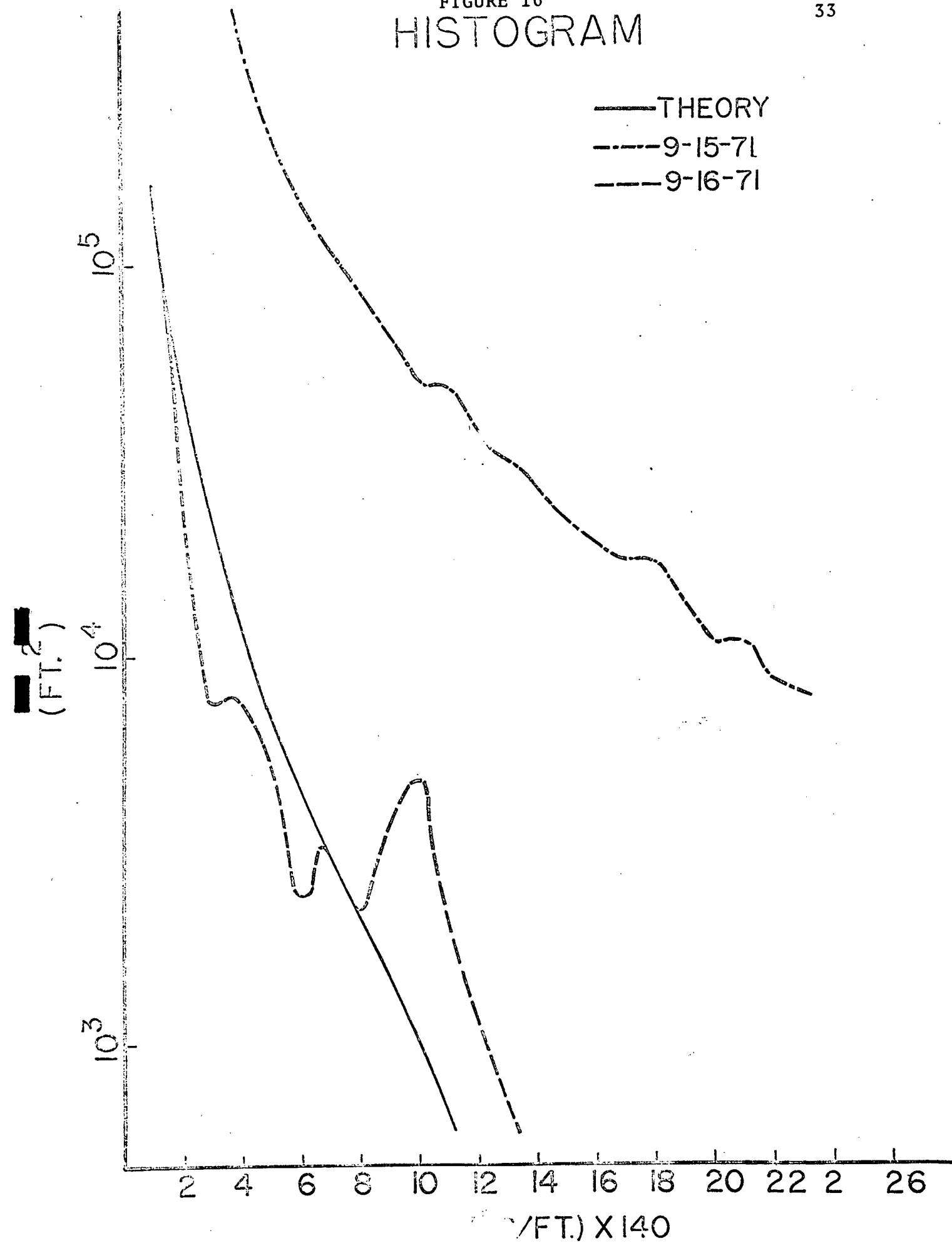


FIGURE 15

FIGURE 16
HISTOGRAM

33



from the boat-mounted PRT data, and typified by Figure 17. The inverse square root curve fits the PRT centerline temperature rather well. Differences among the three histograms are quite large. It should be noted that fish encounter instantaneous, not time- or ensemble-, average plumes.

It is interesting to note that the series of concentric surface thermal fronts, so prominent in the thermal imagery and appearing with varying degrees of clarity on each of the four days during which field operations were conducted, has not been built into any predictive theoretical model of a thermal plume, nor has it been seen (to our knowledge) in laboratory models.

One method of obtaining simultaneous velocity data at many points involves aerial photography of a large number of drogues with appropriate surface markers. A number of these experiments were attempted last summer, using a state-owned mapping plane with a cartographic camera. The plane made up to 15 passes over the plume at five-minute intervals, photographing a large number of drogues seeded by small boats. Positions of the drogues are determined by photogrammetric techniques. Average velocities are accurate to 0.01 ft/sec. An example of the results is shown in Figure 18. Data analysis for other, similar experiments is underway. Automatic analysis techniques are now being developed.

To the extent that fairly rapid temperature changes are important to the biota, the instantaneous plume, rather than a time-average or climatological plume, is also important. The data presented above strongly indicate that the standard methods of measuring characteristics of thermal plumes do not reveal actual large temperature gradients, and also can lead easily to erroneous pictures of the mean plume.

In very calm weather, plumes are dominated at least sometimes either by sharp concentric thermal fronts spreading radially outward or by a wavelike temperature structure which behaves similarly. Although several mechanisms seem reasonable, the causes of these phenomena are not actually known.

It will be difficult to fully characterize or to legislatively regulate the synoptic thermal plume. These are dominated by puffs, meanders or fronts, and the classic jet and plume classifications will not be easy to apply. Further (and especially if thermal gradients are quite important), the "mixing zone" concept, which limits absolute temperature increases (over ambient lake temperature) over a specified value to a certain maximum area, is probably not the most logical tool with which to assess ecological impact.

Finally, we believe that many repeated synoptic velocity and temperature measurements of a full-scale thermal plume are crucial for an adequate understanding of both its mean behavior and the fluctuations from the mean.

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POINT BEACH SEPT. 15, 1971

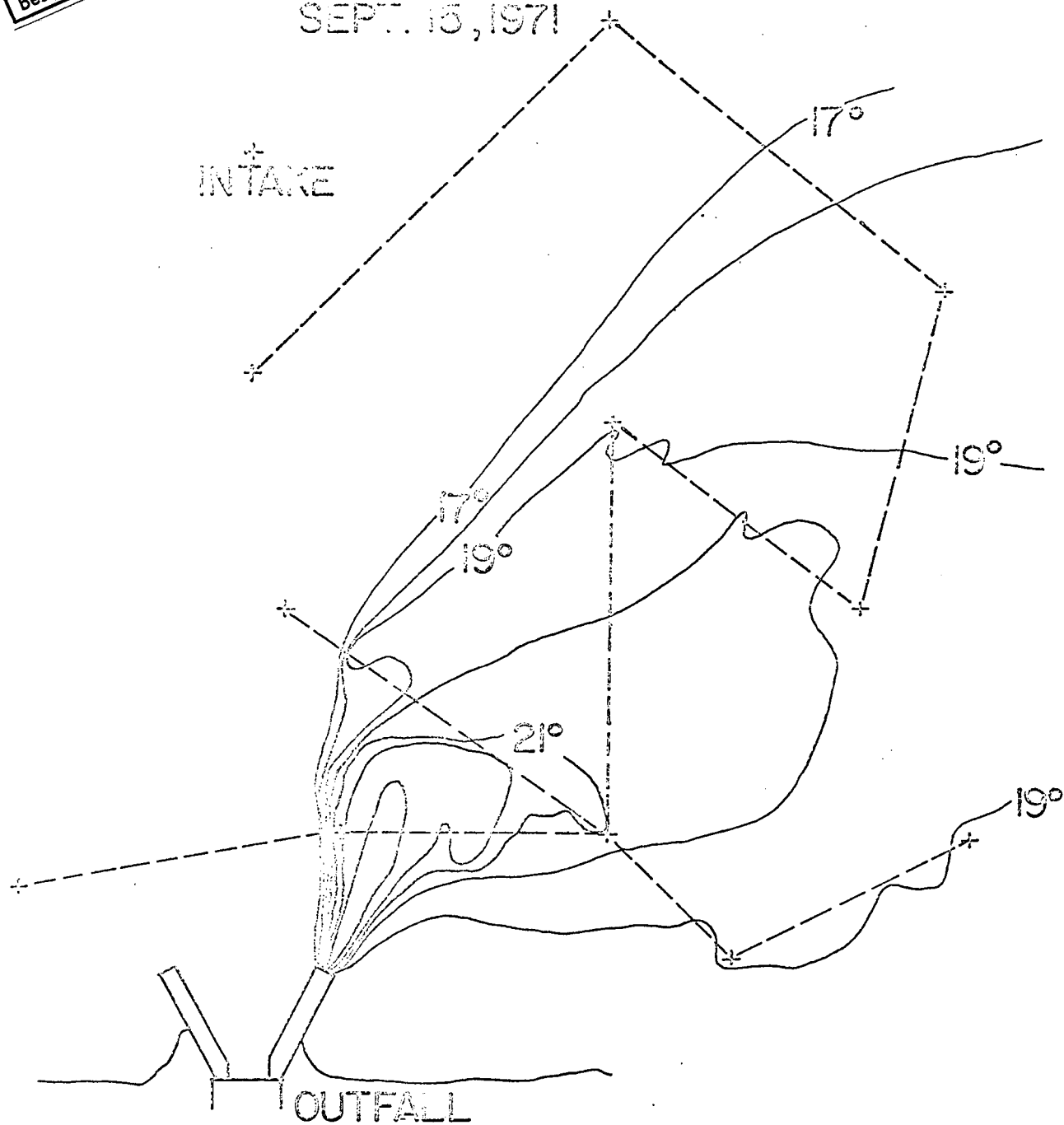


FIGURE 17

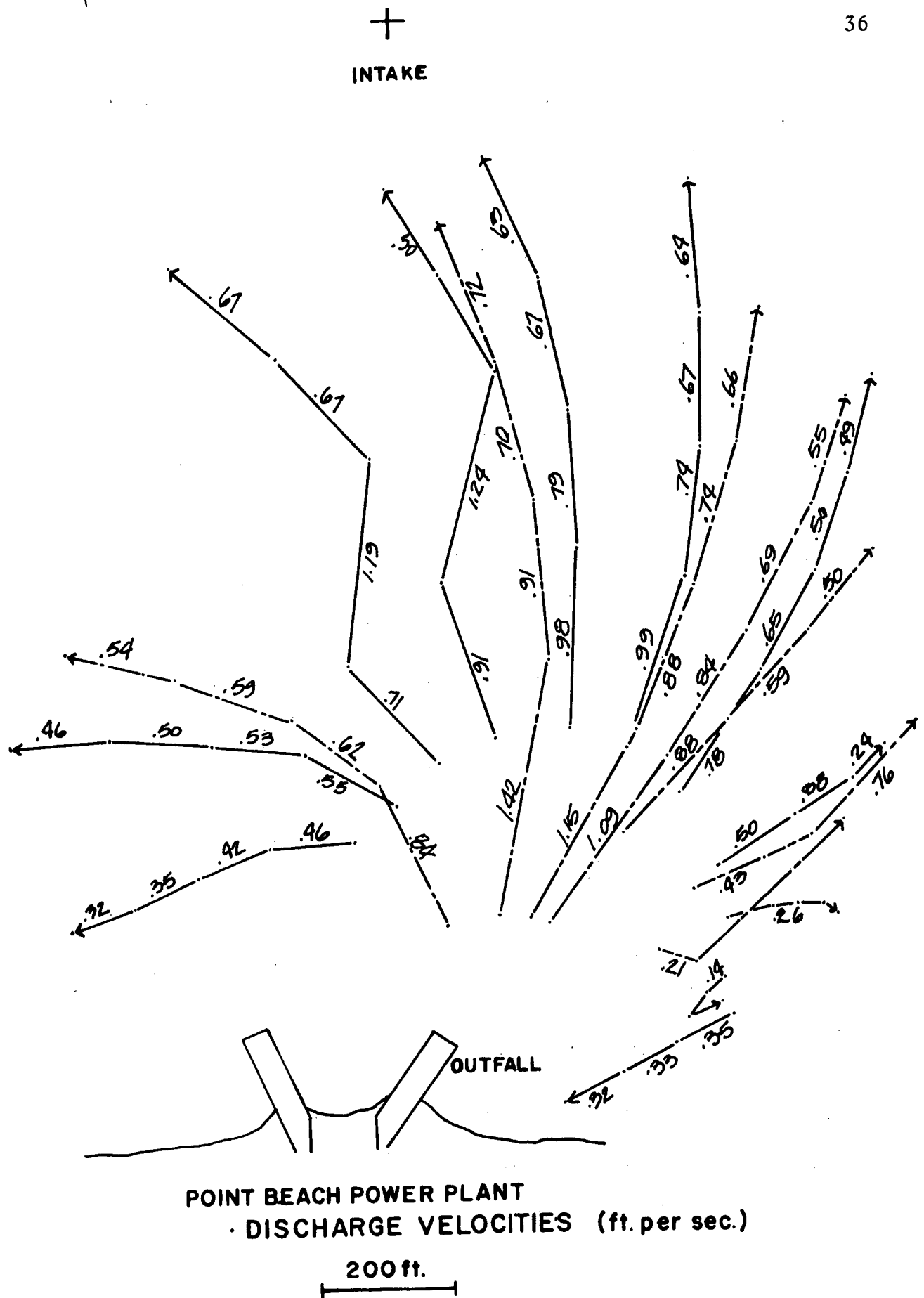


FIGURE 18

These results were reported at the Great Lakes Research Conference in April 1972 (see University of Wisconsin Remote Sensing Program Report No. 16), and a more detailed report on thermal fluctuations has been accepted for publication in Water Resources Research (see University of Wisconsin Remote Sensing Program Report No. 17).

IV. APPLICATION OF REMOTE SENSING TO THE
DETERMINATION OF MIXING ZONE FOR EFFLUENTS
DISCHARGED INTO STREAMS OR RIVERS

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ABSTRACT

Basic goals of this project are: 1) to develop an explicit relationship on the extent of the mixing zone in terms of the outfall, effluent and water body characteristics, and 2) to apply aerial remote sensing methods to the definition of the boundaries and concentrations of waste effluents in the mixing zone. Using this definition of a mixing zone, governmental agencies could establish a reasonable sampling and regulation program for effluent discharges. Through an extensive literature search, a working hypothesis for the extent of the mixing zone as a function of outfall, effluent and water body characteristics has been formulated. Using a laboratory flume, a model of the Weston Power Plant on the Wisconsin River near Rothschild has been constructed and tested. Mathematical models of buoyant jets and plumes, discharging into stationary and moving environments including boundaries, are being analyzed to determine the rate of effluent mixing as a function of distance from the outfall. Intensive aerial remote sensing (photogrammetric and infrared thermal scanning), coupled with detailed ground measurements of waste effluent concentration, temperature and velocity patterns, have been undertaken on the Wisconsin River at the Weston Power Plant and the American Can Company near Rothschild, on the lower Fox River at the Kimberly Clark Paper Mill, in Kimberly, and on the Fox-Illinois River at the Waukesha Sewage Treatment Plant. Good correlation between aerial sensed data and ground measurements has been obtained.

INTRODUCTION

Increasing concern with pollution of our streams, rivers and lakes has led to considerable public and governmental attention to this problem within the last few years. The Federal Water

Pollution Control Act of 1965 (Water Quality Act) and the subsequent development of state water quality guidelines are an outgrowth of this concern. The present State of Wisconsin water quality guidelines (as well as those of other states), regarding the determination of whether discharge of a foreign substance (i.e. biological, chemical or heat) is polluting a stream, river or lake, are somewhat arbitrary in that no consideration appears to be given to the type of effluent, the local flow conditions in the receiving water body, or the type and location of outfall structure.

When a pollutant is introduced into a river, lake or stream, the energy of the effluent discharge and of the receiving water body interact to disperse the substance, thereby reducing its concentration. This dispersal of a pollutant can be envisioned as a two-stage process. In the first region (immediately downstream from the point of discharge), the pollutant is dispersed by the interaction of the physical and flow characteristics of the effluent (i.e. buoyancy, momentum, etc.) and outfall (surface, shoreline, etc.) with these same characteristics in the receiving water body. The first region extends to a distance where the initial physical and flow characteristics of the effluent and outfall are dissipated by the receiving flow field; further dispersal of effluent in the second region is determined by the natural turbulence and velocity distribution in the receiving water body.

Throughout this two-stage process, the waste effluent concentration is being continually diluted until it reaches the level obtainable by total mixing. The extent of a water body over which this degree of dilution occurs is defined as the "mixing zone." Other definitions of a mixing zone, such as the region in which a waste is diluted to a particular concentration, are also used. The new Federal Water Quality Guidelines will probably propose a mixing zone definition based upon the time of exposure of desirable organisms to detrimental waste effluent concentrations.

Basic goals of this research are: 1) to develop an explicit relationship for the extent of the mixing zone as a function of outfall, effluent and water body characteristics, and 2) to apply aerial remote sensing methods to the definition of boundaries and waste effluent concentrations in the mixing zone. This relationship may be used: 1) in establishing definite and rational water quality guidelines; 2) in developing sampling and regulation programs by governmental agencies; and 3) in designing and locating outfalls by industries and municipalities. To accomplish these goals, an integrated program of mathematical and laboratory modeling and field testing is being carried out.

SPECIFIC PROJECT OBJECTIVES

(1) To make ground and aerial measurements of waste effluent concentrations and velocity patterns in the "mixing zone" at various sites throughout Wisconsin.

(2) To use these field observations to define the "mixing zone" and to determine airborne photographic and infrared sensor definition of "mixing zone" boundaries and waste effluent concentrations.

(3) To conduct a series of laboratory model studies, for the purpose of duplicating the "mixing zone" characteristics observed in the field.

(4) To develop a mathematical model of concentration and velocity patterns for an effluent discharged into a water body, taking into account the geometrical, physical and flow characteristics of the water body and effluent.

(5) To synthesize results from field and laboratory observations and from mathematical modeling into a relationship for the extent of the "mixing zone" in terms of known or measurable river, outfall and effluent parameters.

(6) To develop a reasonable sampling and regulation program for waste effluent discharges in cooperation with State and Federal governmental agencies.

PROJECT RESULTS

During 1971-72 laboratory and field observations of the mixing of effluents discharged into river environments were undertaken. Simple mathematical models of the first region of the "mixing zone" have been studied. Field measurements of effluent concentrations and velocity distributions downstream of the outfalls have been analyzed regarding the extent of the "mixing zone" and its dependence on outfall, effluent and river characteristics. Analysis of aerial photography and thermal imagery has provided the methodology for correcting 35mm film for camera, processing and atmospheric effects; has led to a direct correlation of film response to suspended solids concentration; and has shown that aerial sensors yield both qualitative and quantitative information on the "mixing zone." Specific results from each phase of the project are discussed in the paragraphs below.

A. Laboratory Model Studies

During 1971-72 a continuation of model studies conducted in 1970-71 on warm effluent waste discharges was carried out. Details of the model and measuring techniques may be found in the 1970-71 progress report. The following is a brief summary of 1970-71 model tests. A more complete description of these tests may also be found in the 1970-71 progress report.

Three series of model tests were carried out. Series A was a general set of experiments to study the influences of certain river, effluent and outfall parameters on concentration patterns in and extent of the "mixing zone." Series B and C were concerned with developing and testing a model, including

appropriate modeling criteria, for simulating the "mixing zone" at the Weston Power Plant on the Wisconsin River. Series A established general trends and dependencies of the "mixing zone" as a function of river, effluent and outfall parameters. The experimental work of Series B indicated that the Froude and Densimetric Froude modeling laws can be used for thermal mixing zones to give reasonably good results.

One problem encountered with the Series B tests was that the Reynolds number in the model was very low as compared to the Reynolds number of the prototype. The Wisconsin River at Rothschild has a Reynolds number of about 500,000 while the Reynolds number in the Series B model was about 500, which is in the transition range from laminar to turbulent flow. Thus the level of turbulence in the model was very much less than that of the prototype. In order to alleviate this problem, Series C tests were designed to increase the Reynolds number. This necessitated the use of a vertical scale distortion, and hence the vertical scale was made larger than the horizontal scale. Series C tests were just being started at the time of the 1970-71 progress report.

In the continuing study of Series C tests, the horizontal scale ratio was maintained at 1:150 as in previous tests. Several vertical to horizontal scale distortions were used, ranging from 1.25:1 to 7:1. More specifically, three types of model tests were carried out:

- (1) Model tests based upon only the Densimetric Froude number with vertical to horizontal scale distortions of 3 to 1, 5 to 1, and 6 to 1.
- (2) Model tests based upon the Froude number and the Densimetric Froude number with vertical to horizontal scale distortions of 5 to 1 and 7 to 1.
- (3) Model tests based upon only the Euler number (which requires that velocity ratios, model and prototype, be equal to 1, and it is used for flow situations where there are large exchanges of momentum between effluent and river) with a vertical to horizontal scale distortion of 1.25 to 1.

Based upon the Froude and Densimetric Froude number model tests, lateral diffusion coefficients were also computed by: 1) analyzing the apparent Gaussian surface temperature distributions, and 2) the use of the empirical equation

$$D_y = K V_* d$$

in which D_y is the lateral diffusion coefficient, K is a constant dependent on channel geometry (taken equal to 0.23 from the work of others), V_* is the friction velocity, and d is the depth of flow. It was found that lateral diffusion coefficients determined by method 1) were much larger than those from method 2). This is not surprising, however, when one considers that

method 2) determination assumes that vertical temperature structure is uniform when, in fact, there is significant vertical stratification. Hence the lateral spread is larger than that which would be predicted by the diffusion coefficient from Figure 1.

In addition to conclusions derived from Series A and Series B model tests, which are summarized in the 1970-71 progress report, the following conclusions are made:

(1) The use of a vertically distorted model increases the Reynolds number of the model river and, therefore, the turbulence level in the model which more closely approximates prototype conditions.

(2) The Euler model law may be important for modeling the initial reach of the "mixing zone" where effluent discharge momentum is significant. However, in the present study of the Weston Power Plant, the initial momentum of the effluent jet is largely dissipated by a small bay in which the outfall is located. Hence the Euler model law is not important.

(3) A distorted Densimetric Froude model can be used to reasonably define the gross features of the spread of a warm water effluent discharged into a river (i.e. the "mixing zone") in which large exchanges of momentum between effluent and river are not present. There are, however, differences in the fine structure of the cross sectional temperature distributions.

(4) Extreme care must be exercised in evaluating lateral diffusion coefficients under conditions in which vertical stratification exists.

The tests with model conditions determined by equality of Froude numbers for the river flow and by equality of densimetric Froude numbers for the effluent discharge and temperature gave the best comparison with prototype observations. A typical plot of surface isotherms for this modeling condition, scaled up to field conditions and compared with field observations of 26 August 1970, is shown in Figure 1. Surface temperature patterns are similar in shape between the model and the prototype; however, the model isotherms have spread across the river more than the prototype isotherms. This increased spread in the model, which is evident close to the outfall in Figure 1, resulted from incomplete similarity in the bay region (model outfall velocities were approximately 50% greater than required from similarity, and the outfall geometry was not completely similar to the prototype). Furthermore, the bend in the river and depth variations across the river on the prototype were not modeled. Finally, since at the Weston plant the initial momentum of the effluent jet is largely dissipated in the small bay adjacent to the river into which the effluent is discharged, one would expect the importance of the Euler number to be much less significant than the Froude and Densimetric Froude numbers.

- LEGEND**
- FIELD ISOTHERMS
 - - - MODEL ISOTHERMS
 - ~ MIXING ZONE BOUNDARY (SURFACE)
 - - - - EFFLUENT BOUNDARY
 - FROM AERIAL PHOTOGRAPHS

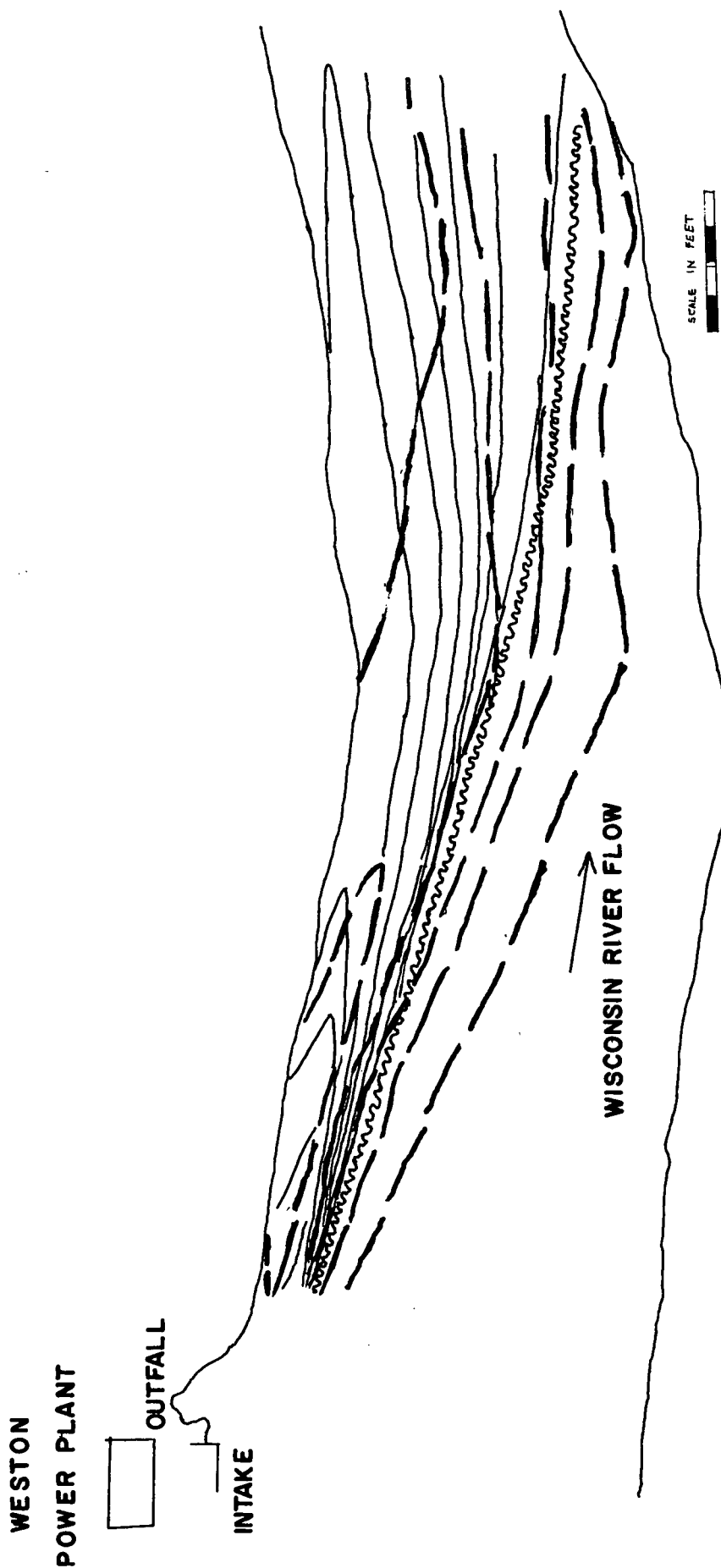


FIGURE 1

COMPARISON OF MODEL AND FIELD SURFACE ISOTHERM PATTERNS
WESTON POWER PLANT, AUGUST 26, 1970
FOR MODEL TEST SERIES 2.2.A

It was found that a significant vertical stratification develops downstream from the outfall. This phenomenon was also observed in the field; however, there are differences in the detailed structure from the prototype temperature distributions. A direct comparison of model and prototype cross sectional distributions is not possible, since model observations were not made at the sections corresponding to the field observations.

B. Field Studies

During the summer of 1971, field surveys of waste effluent concentrations and velocity patterns, coupled with 35mm color aerial photography, were made at the Weston Power Plant and the Rothschild Mill of American Can Company on the Wisconsin River, the Waukesha Sewage Treatment Plant on the Fox-Illinois River, and the Kimberly Mill of Kimberly-Clark Corporation on the lower Fox River. A total of eight surveys were conducted; additional surveys were required to establish ground control and the hydrography of each site. The date, location and general characteristics for each survey are listed in Table 1. Data from each of these surveys has been reduced, plotted and subjected to preliminary analysis. In addition, four surveys of surface temperature patterns, using aerial thermal imagery, were carried out in the fall of 1971 and the spring of 1972 at the Weston Power Plant and Kimberly Clark Paper Mill sites. General characteristics of these four surveys are listed in Table 2.

1. Weston Power Plant. The Weston Power Plant is a 135 megawatt steam electric, fossil-fueled power plant located on the Wisconsin River south of Wausau near Rothschild. The plant, which is approximately 40% efficient, takes in condenser cooling water through an intake located just upstream from the outfall. The plant effluent is discharged from a submerged (approximately 3 feet below the river surface) 6' x 8' box opening into a small bay which connects to the river at an angle of approximately 45°. A detailed summary of the river, effluent and outfall characteristics and parameters for the Weston Power Plant surveys are given in Table 3.

The two velocity and temperature surveys supplemented four surveys carried out in the summers of 1969 and 1970 (see 1970-71 progress report). The 22 July 1971 survey was extended farther downstream than previous surveys; the 31 August 1971 survey was limited to the area inside the small bay. Temperature and velocity measurements were made from a boat which was located by triangulation from two shore stations. Instruments used for the temperature and velocity measurements are listed in Table 3.

Based on boat measurements for the two ground surveys, surface temperature patterns and vertical temperature and velocity distributions have been plotted, the warm water discharge boundary has been determined, and the flow within the

TABLE 1
GENERAL SUMMARY OF THE SURVEYS

Date	Site	Type & Character of Effluent & Outfall	River Characteristics
22 July 1971	Weston Power Plant Wisconsin River near Wausau	Submerged bank discharge, Condenser cooling water, Temperature 129°C warmer than river, Discharge of 187 cfs	500' wide 5' deep flow rate 3,150 cfs
3 August 1971	Rothschild Paper Mill Wisconsin River near Wausau	Bank submerged discharge, Pulp mill effluent, Temperature 10°C warmer than river, Discharge of 6.7 cfs	450' wide 5-20' deep flow rate 2,603 cfs
11 August 1971	Kimberly Paper Mill Lower Fox River near Appleton	Bank discharge, Paper waste effluent, Temperature 11°C warmer than river, Discharge of 15 cfs	600-1,000' wide 5-10' deep flow rate 1,824 cfs
12 August 1971	Rothschild Paper Mill Wisconsin River near Wausau	Bank submerged discharge, Pulp mill effluent, Temperature 9°C warmer than river, Discharge 6.2 cfs	450' wide 5-20' deep flow rate 2,670 cfs
27 August 1971	Kimberly Paper Mill Lower Fox River near Appleton	Bank discharge, Paper waste effluent, Temperature 14°C warmer than river, Discharge of 18 cfs	600-1,000' wide 5-10' deep flow rate 1,814 cfs
31 August 1971	Weston Power Plant Wisconsin River near Wausau	Submerged bank discharge, Condenser cooling water, Temperature 13.1°C warmer than river, Discharge of 92 cfs	bay area river flow rate of 2,360 cfs
1 September 1971	Rothschild Paper Mill Wisconsin River near Wausau	Bank submerged discharge, Pulp mill effluent, Temperature 11°C warmer than river, Discharge of 7.1 cfs	450' wide 5-20' deep flow rate 2,620 cfs
10 September 1971	Waukesha Sewage Treatment Plant, Fox-III. River at Waukesha	Bank discharge (uniform over river depth), Municipal sewage, Temperature 4°C colder than river Discharge of 16.2 cfs	80' wide, 1' deep flow rate 13.5 cfs

TABLE 2

SUMMARY OF AERIAL THERMAL SCANNING SURVEYS

Date	Site	Type & Character of Effluent & Outfall	River Characteristics
13 September 1971	Weston Power Plant Wisconsin River near Wausau	Submerged bank discharge, Condenser cooling water, Temperature 10.5°C warmer than river, Discharge of 92 cfs	500' wide flow rate of 2,700 cfs
14 September 1971	Kimberly Paper Mill Lower Fox River near Appleton	Bank discharge, Paper waste effluent, Temperature 14°C warmer than river, Discharge of 14.2 cfs	600'-1,000' wide flow rate of 1,700 cfs
16 September 1971	Kimberly Paper Mill Lower Fox River near Appleton	Bank discharge, Paper waste effluent, Temperature 14°C warmer than river, Discharge of 14.4 cfs	600'-1,000' wide flow rate of 1,640 cfs
10 April 1972	Weston Power Plant Wisconsin River near Wausau	Submerged bank discharge, Condenser cooling water, Temperature 15°C warmer than river, Discharge of 187 cfs	500' wide flow rate of 5,100 cfs

TABLE 3

CONDITIONS ON FIELD SURVEYS AT WESTON POWER PLANT

Date of Survey		22 July 1971	31 August 1971	13 September 1971*	10 April 1972*
River and Weather Data					
River Width	500'	500'	500'	500'	500'
River Depth	5'	5'	5'	est. 5'	est. 6'
Length of Measurement	4,350'	50'	50'	1.5 miles	1.5 miles
Flow Rate	3,150 cfs	2,370 cfs	2,370 cfs	2,700 cfs	5,100 cfs
Average Velocity	0.96 fps	0.95 fps	0.95 fps	1.08 fps	1.7 fps
Reynolds Number	0.608×10^{-4}	0.475×10^{-4}	0.475×10^{-4}	0.54×10^4	1.02×10^4
River Water Temperature	23.0°C	20.0°C	20.0°C	21.5°C	20°C
Air Temperature	31°C	15°C	15°C	15°C	50°C
Wind	3 mph	5 mph	5 mph	calm	5 mph
Effluent Conditions at Outfall					
Type of Effluent	Cooling Water from Power Plant				
Shape & Size of Outfall	6' x 8' rectangular outlet				
Effluent Discharge	190 cfs	92 cfs	92 cfs	92 cfs	187 cfs
Average Effluent Velocity	3.9 fps	1.9 fps	1.9 fps	1.9 fps	3.9 fps
Reynolds Number	2.71×10^4	1.33×10^4	1.33×10^4	1.33×10^4	2.71×10^4
Densimetric Froude Number	17.9	4.5	4.5	4.5	17.0
Velocity Ratio	4.05	2.0	2.0	1.76	2.30
Effluent Temperature	35.9°C	33.1°C	33.1°C	32.0°C	17.0°C
Measurement and Equipment					
Velocity	Gurley, cup-type current meter with direct readout				
Temperature	Whitney Underwater Thermometer				
Position	2 transits (triangulation)				

*Thermal scanning surveys

boundary and the heat flow with respect to river have been calculated.

Thermal imagery from the two thermal flights has been densitized and, using a UNIVAC 1108 computer, has been coded and printed. Using a coloring scheme, surface temperatures and contours have been plotted according to the computer print-outs and ground temperature measurements at two stations on the survey dates.

Based upon the data and preliminary analysis of the 1971 results, the following conclusions can be made:

(1) In the bay region close to the outfall, the cooling water discharge is well mixed vertically with strong temperature gradients and cooler temperatures along the north side of the bay. At the mouth of the bay the isotherm pattern shows strong stratification with river water intruding into the bay. Maximum temperatures and velocities occur along the south edge of the bay, suggesting that the discharge is being directed along this edge.

(2) As the river flow rate on the 22 July 1971 survey was higher than those of the previous summer surveys, the rate of increase in the surface width and the flow within the boundary of the warm water discharge with distance downstream from the outfall was slower than in previous surveys.

(3) The rate of increase of the surface width of the effluent discharge, obtained from the two thermal scanning surveys, is in agreement with the results of ground surveys for comparable river flows.

Results of the above surveys complement and extend the work from previous summers (see 1970-71 progress report).

2. Waukesha Sewage Treatment Plant. The Waukesha plant is a municipal sewage treatment plant of the city of Waukesha which handles approximately 16 cfs. The plant discharges sewage into the Fox-Illinois River on the east bank through a 30-inch diameter culvert. The Fox-Illinois River is very winding in this stretch, and the outfall discharges at the end of a double bend. A detailed summary of the river, effluent and outfall characteristics and parameters from the Waukesha Sewage Treatment Plant survey is given in Table 4.

This survey concentrated on the area close to the outfall; a section 655 feet downstream of the outfall was taken, however, in order to tie this survey to previous surveys (see 1970-71 progress report). Velocity and temperature measurements were made by wading across the river at various sections, since the river was shallow. These sections were located with respect to the outfall, and measurements were made along a calibrated rope stretched across the river at each section. Instruments used for the temperature and velocity measurements are listed in Table 4.

TABLE 4
CONDITIONS ON FIELD SURVEY AT
WAUKESHA SEWAGE TREATMENT PLANT

Date of Survey		10 September 1971	
River and Weather Data			
River Width		80'	
River Depth		0.8'	
Length of Measurement		650'	
Flow Rate		13.5 cfs	
Average Velocity		0.7 fps	
Reynolds Number		0.56×10^5	
River Water Temperature		26°C	
Air Temperature		20°C	
Wind		calm	
Effluent Conditions at Outfall			
Type of Effluent		Municipal sewage waste	
Shape & Size of Outfall		30' diameter circular outfall	
Effluent Discharge		16.2 cfs	
Average Effluent Velocity		3.3 fps	
Effluent Temperature		22°C	
Reynolds Number		8.2×10^5	
Densimetric Froude Number		11.6	
Velocity Ratio		4.72	
Measurements and Equipment			
Velocity	Gurley, cup-type current meter with direct readout		
Temperature	Whitney underwater thermometer		
Position	Transit (location) and nylon rope (lateral position in a cross section)		

Concentration contours with respect to river and outfall conditions were obtained from the temperature measurements. Vertical distributions of temperature and velocity were obtained at six sections across the river. The waste plume boundary was determined from observed data. Flow within the boundary and effluent mass flux was calculated at each of the six sections.

Based upon this data and analysis, the following conclusions can be made:

(1) The waste effluent initially expands in width (laterally) very rapidly with distance from the outfall; about 30 feet from the outfall the discharge has spread over approximately 60% of the river (proportional to ratio of plant discharge to plant plus river discharge). Beyond this point the effluent spreads laterally only very slowly.

(2) The turbulent eddy structure is very strong near the outfall.

(3) The effluent is well mixed with depth due to the shallowness of the river and the level of river turbulence.

Results of this survey complement and extend the work from previous summers (see 1970-71 progress report).

3. American Can Company Paper Mill. During the summer of 1971, three surveys were carried out at the Rothschild paper mill of American Can Company. This plant has a total effluent discharge of approximately 20 cfs through its nine outfalls into the Wisconsin River. The main flux mill outfall, into which a dye tracer was injected, discharges about one-third of the total discharge. The outfall is a 3' x 3' square concrete conduit. A detailed summary of the river, effluent and outfall characteristics and parameters for each of the surveys is given in Table 5.

On each of the three surveys the velocity, temperature and dye tracer distributions were measured in the vicinity of and downstream from the outfall. A dye tracer (Rhodamine WT) was added to the main outfall in order to compare dye concentrations with effluent mixing patterns obtained from temperature measurements, for the effluent is primarily suspended and dissolved solids, and the large dilution close to the outfall discharge resulted in a small temperature rise above the river. These measurements were made from a boat located by triangulation from two shore stations. The instruments used for velocity, temperature and dye measurements are indicated in Table 5.

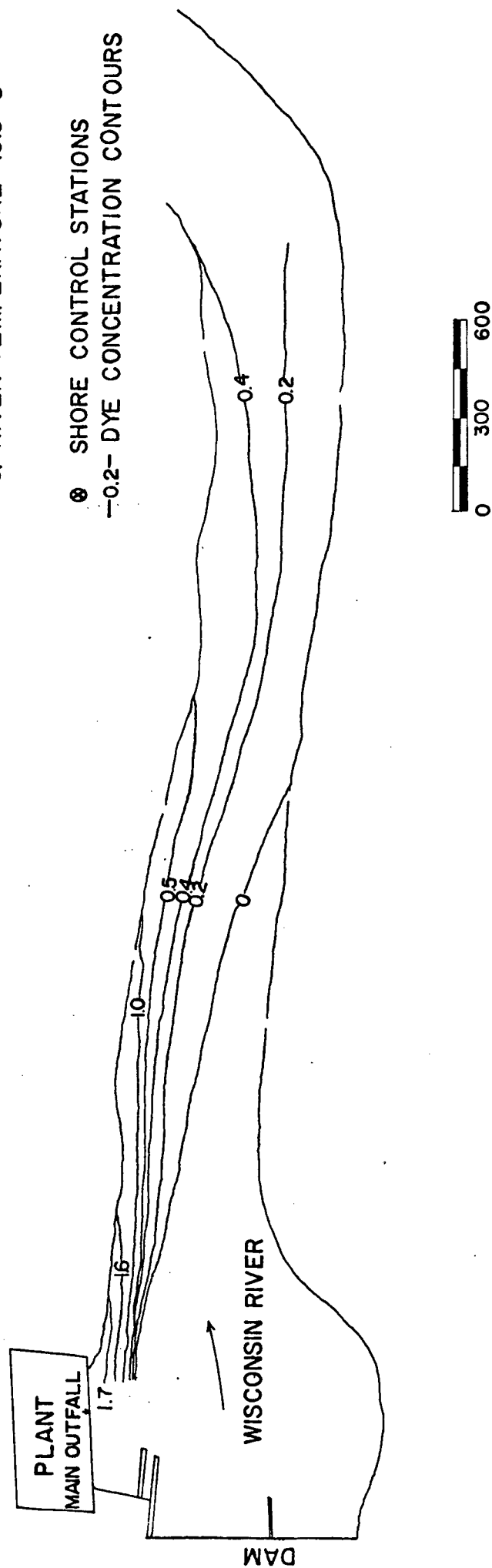
Figure 2 shows dye concentration contours at one foot below the water surface for the 1 September 1971 survey. This survey is typical of the three surveys. Vertical distributions of velocity, temperature and dye concentration were obtained at four sections for the 3 and 12 August surveys, and at five sections for the 1 September survey. Based on these observations,

TABLE 5
 INFORMATION FROM FIELD SURVEYS
 ON THE WISCONSIN RIVER AT ROTHSCILD

Date of Survey	3 August 1971	12 August 1971	1 September 1971
River and Weather Data			
River Width	450'	450'	450'
River Depth	5-20'	5-20'	5-20'
Length of Measurement	1,200'	2,640'	3,600'
Flow Rate	2,603 cfs	2,670 cfs	2,620 cfs
Average Velocity	1.0 fps	1.0 fps	1.0 fps
Reynolds Number	10^6	10^6	10^6
River Water Temperature	19.6°C	22.5°C	19.8°C
Air Temperature	25°C	25°C	20°C
Wind	calm	calm	calm
Effluent Conditions at Outfall			
Type of Effluent	Pulp waste		
Shape & Size of Outfall	3' x 3' square		
Effluent Discharge	6.7 cfs	6.2 cfs	7.1 cfs
Effluent Temperature	30.2°C	31.0°C	31.0°C
Average Effluent Velocity	0.74 fps	0.69 fps	0.79 fps
Reynolds Number	2.2×10^5	2.0×10^5	2.4×10^5
Velocity Ratio	0.74	0.69	0.79
Measurement and Equipment			
Velocity	Gurley, cup-type current meter with direct readout		
Temperature	Whitney under thermometer		
Dye Concentration	Fluorometer		
Position	Transits		
Others		aerial photos	

OPERATING CONDITIONS:

- 1) OUTFALL DISCHARGE 7.1 CFS
- 2) EFFLUENT TEMPERATURE 31°C
- 3) EFFLUENT DYE CONCENTRATION 55.5 PPB
- 4) RIVER FLOW RATE 2620 CFS
- 5) RIVER TEMPERATURE 19.8°C



DYE CONCENTRATION PATTERN AT 1-FOOT BELOW WATER SURFACE
ROTHSCHILD PAPER MILL

SEPT. 1, 1971

FIGURE 2

the boundary of the waste plume, b , and the flow within this boundary, Q , have been determined at each of the cross sections. The results for b and Q at the sections for which the effluent did not spread over the whole width of the river are shown in Figures 3 and 4. Dye concentration fluxes through each cross section have been calculated.

Based upon an analysis of this data, the following preliminary conclusions can be made:

(1) Due to the special structure (floating surface skimmer) near the outfall, the initial dilution was very high; in addition, the mixing pattern was unsteady and irregular. As a result, temperature was not adequate to indicate the rate of mixing, and a dye tracer was used.

(2) Width of the waste plume increased with distance from the outfall to the $1/3$ power.

(3) Flow within the boundary of the effluent discharge increased very slowly until about 700 feet from the outfall, after which it increased with distance from the outfall to the $2/3$ power; this behavior appears to result from an old training wall which extends from the dam to about that location and is submerged.

4. Kimberly-Clark Paper Mill. The Kimberly Paper Mill of Kimberly-Clark Corporation has a total of 25 outfalls, four of which are located on the upstream side of Cedars Dam (see Figures 5 and 6) and 21 of which are located at the mill and along the south bank downstream of the dam. Discharges from the outfalls on the downstream side of the dam combine together into one plume along the south bank of the river. A large proportion of the total plant discharge (60-70%) is from the main mill outfall (effluent from four paper machines and one paper coater), which is a U-shaped conduit having an area equivalent to a two-foot diameter circle. A detailed summary of the river, effluent and outfall characteristics and parameters for each of the surveys is given in Table 6.

On each of the ground surveys, measurements were made of the velocity, temperature and dye tracer distributions in the vicinity and downstream of the plant. Dye tracer (Rhodamine WT) was added to the main mill outfall in order to compare the dye concentration patterns with the effluent mixing patterns obtained from the temperature measurements, for the effluent is primarily suspended and dissolved solids. Ground measurements were made from a boat, located by triangulation from two shore stations. Instruments used for the temperature, velocity and dye measurements are listed in Table 6. On each of the two thermal flights, simultaneous temperature measurements at two ground stations were made in order to calibrate the imagery.

Figures 5 and 6 show the dye concentration pattern and effluent temperature concentration pattern one foot below the

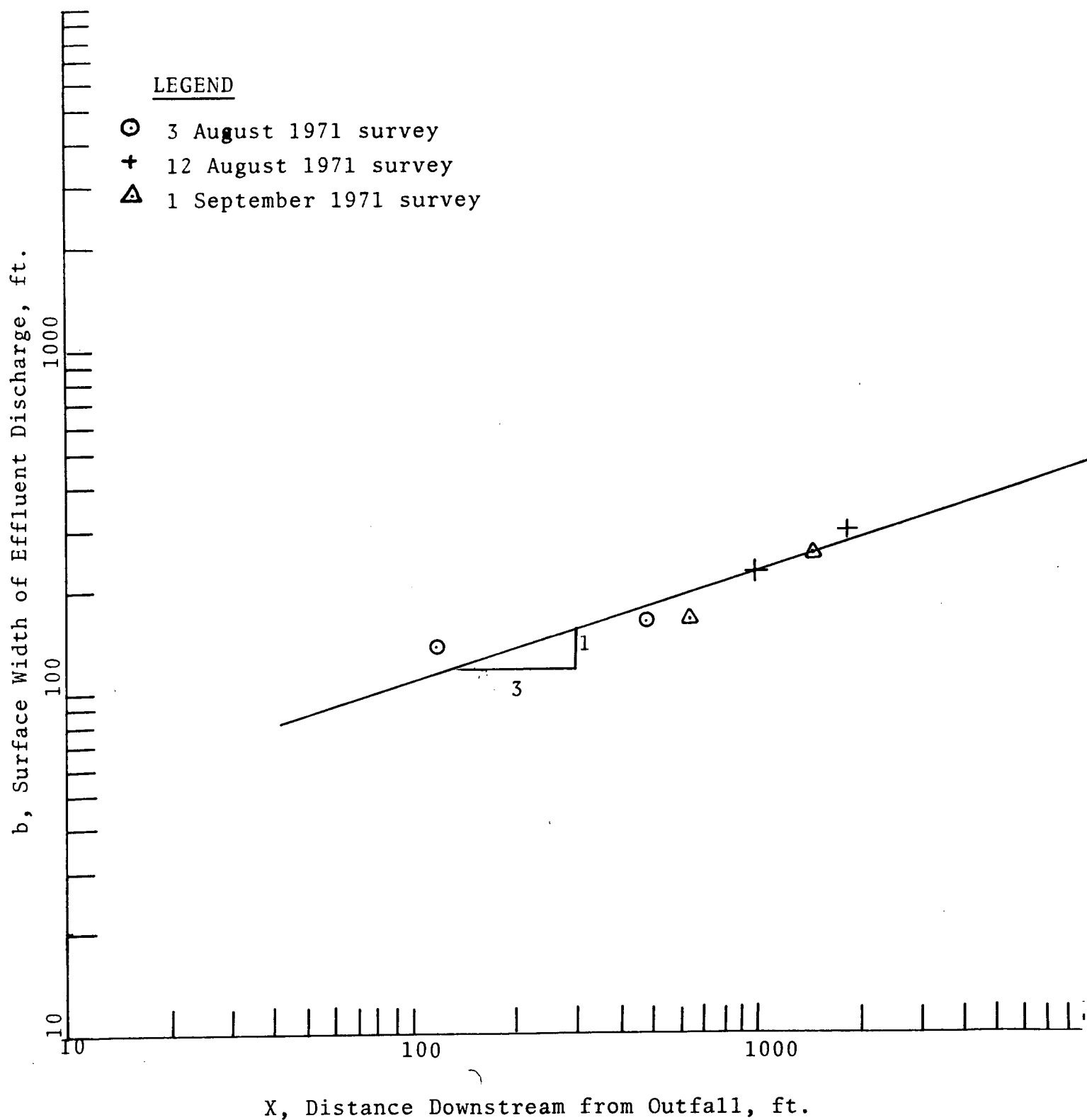


FIGURE 3 - VARIATION OF SURFACE WIDTH OF EFFLUENT DISCHARGE WITH DISTANCE FROM OUTFALL, AMERICAN CAN COMPANY PAPER MILL, ROTHSCHILD, 1971 SUMMER SURVEYS.

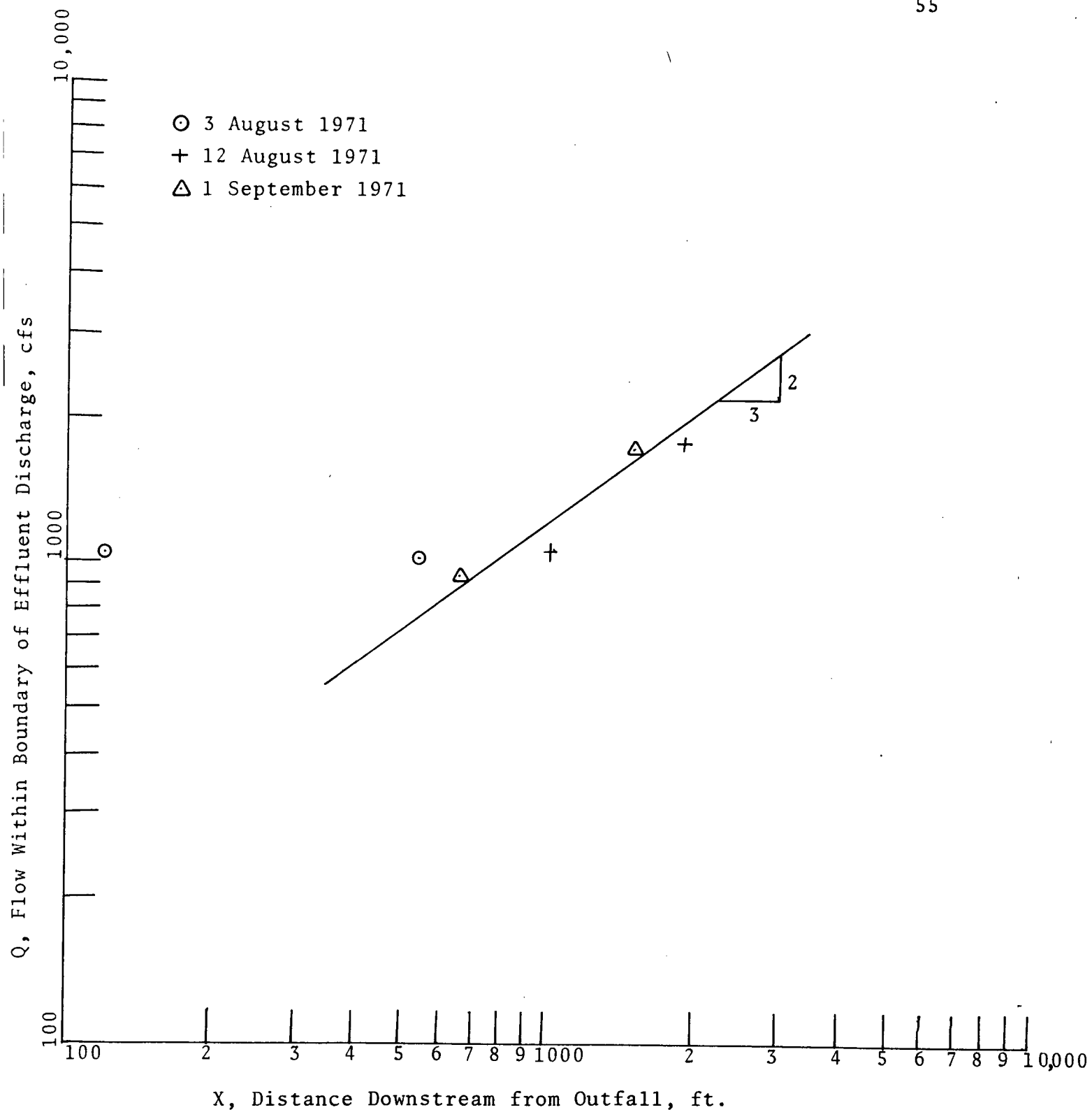


FIGURE 4

VARIATION OF FLOW WITHIN BOUNDARY OF EFFLUENT DISCHARGE WITH
DISTANCE FROM OUTFALL, AMERICAN CAN COMPANY PAPER MILL,
ROTHSCHILD, 1971 SUMMER SURVEYS.

TABLE 6
CONDITIONS ON FIELD SURVEYS
AT KIMBERLY CLARK PAPER MILL

Date of Survey	11 August 1971	27 August 1971	14 September 1971*	16 September 1971*
River and Weather Data				
River Width	600-1,000'	600-1,000'	600-1,000'	600-1,000'
River Depth	5-10'	5-10'	5-10'	5-10'
Length of Measurement	650'	2,900'	2,000'	2,000'
Flow Rate	1,824 cfs	1,814 cfs	1,700 cfs	1,640 cfs
Average Velocity	1 fps	1 fps	1 fps	1 fps
Reynolds Number	7.5×10^5	7.5×10^5	7.5×10^5	7.5×10^5
River Water Temperature	24.2°C	20.5°C	22.0°C	21.2°C
Air Temperature	18°C	16°C	18°C	12°C
Wind	10 mph	8 mph	9 mph	7 mph
Effluent Conditions at Main Mill Outfall				
Type of Effluent	Paper Waste			
Shape & Size of Outfall	U-drain equivalent to 2' diameter circle			
Effluent Discharge	15.0 cfs	15.0 cfs	14.2 cfs	14.4 cfs
Average Effluent Velocity	4.77 fps	4.77 fps	4.51 fps	4.58 fps
Reynolds Number	9.5×10^5	9.5×10^5	9.0×10^5	9.2×10^5
Velocity Ratio	4.77	4.77	4.51	4.51
Effluent Temperature	35.5°C	35.5°C	35.5°C	35.5°C
Measurement and Equipment				
Velocity	Gurley, cup-type current meter with direct readout			
Temperature	Whitney underwater thermometer			
Dye Concentration	Fluorometer			
Position	Transits (triangulation)			
Others	aerial photos taken	aerial photos taken	aerial photos taken	aerial photos taken

*Thermal scanning surveys

KIMBERLY MILL SITE

DYE CONCENTRATION PATTERN (1 ft. below surface)
AUG. 27, 1971 SURVEY

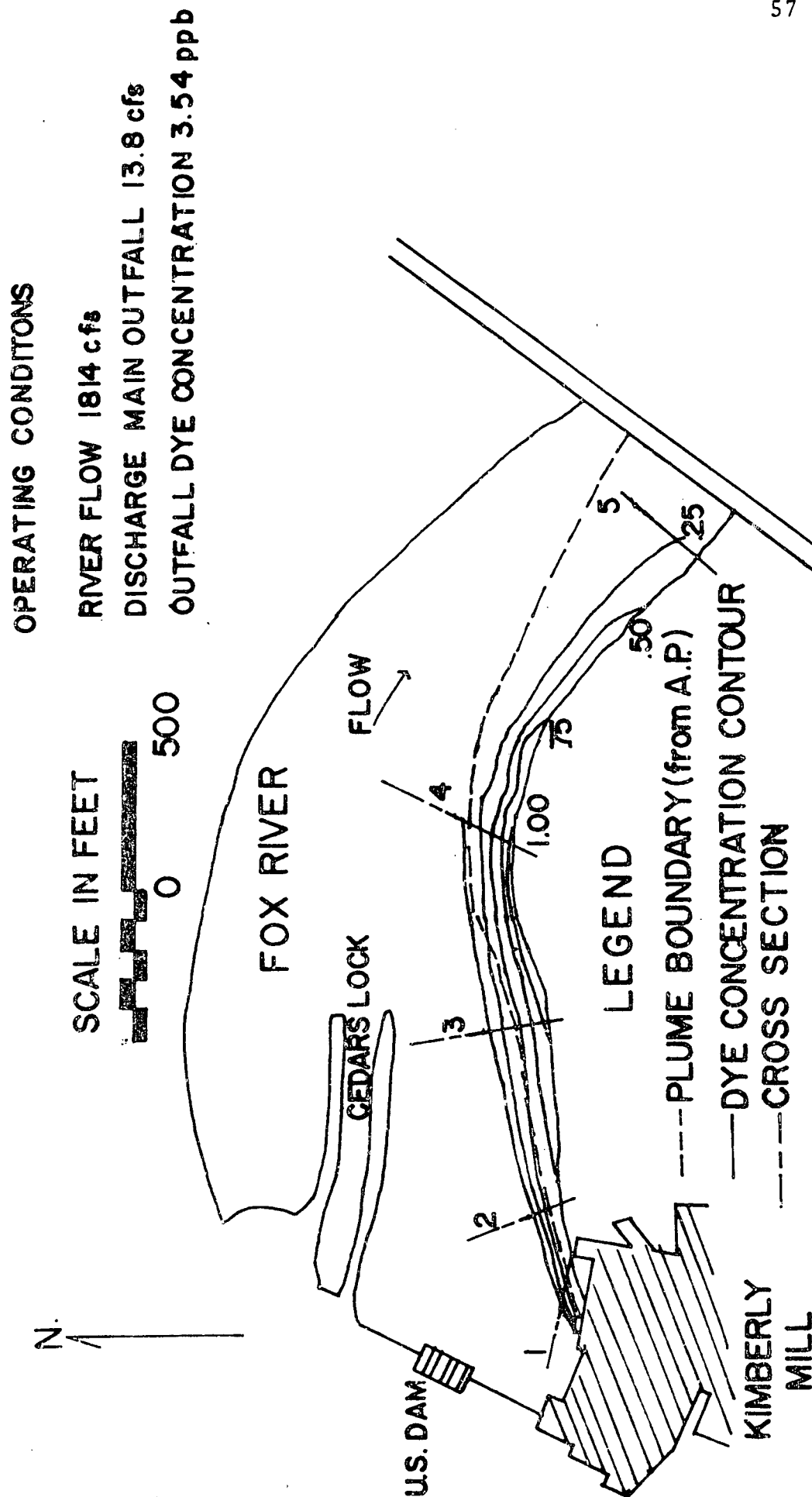


FIGURE 5 - SURFACE PATTERN OF EFFLUENT DYE TRACER

KIMBERLY MILL SITE

CONCENTRATION PATTERN (1 foot below surface)
DETERMINED FROM TEMP. MEASUREMENTS
AUG. 27, 1971 SURVEY

OPERATING CONDITIONS
RIVER TEMP 20.35-20.7 °C
RIVER DISCHARGE 1814 CFS
EFFLUENT TEMP.
EFFLUENT DISCHARGE

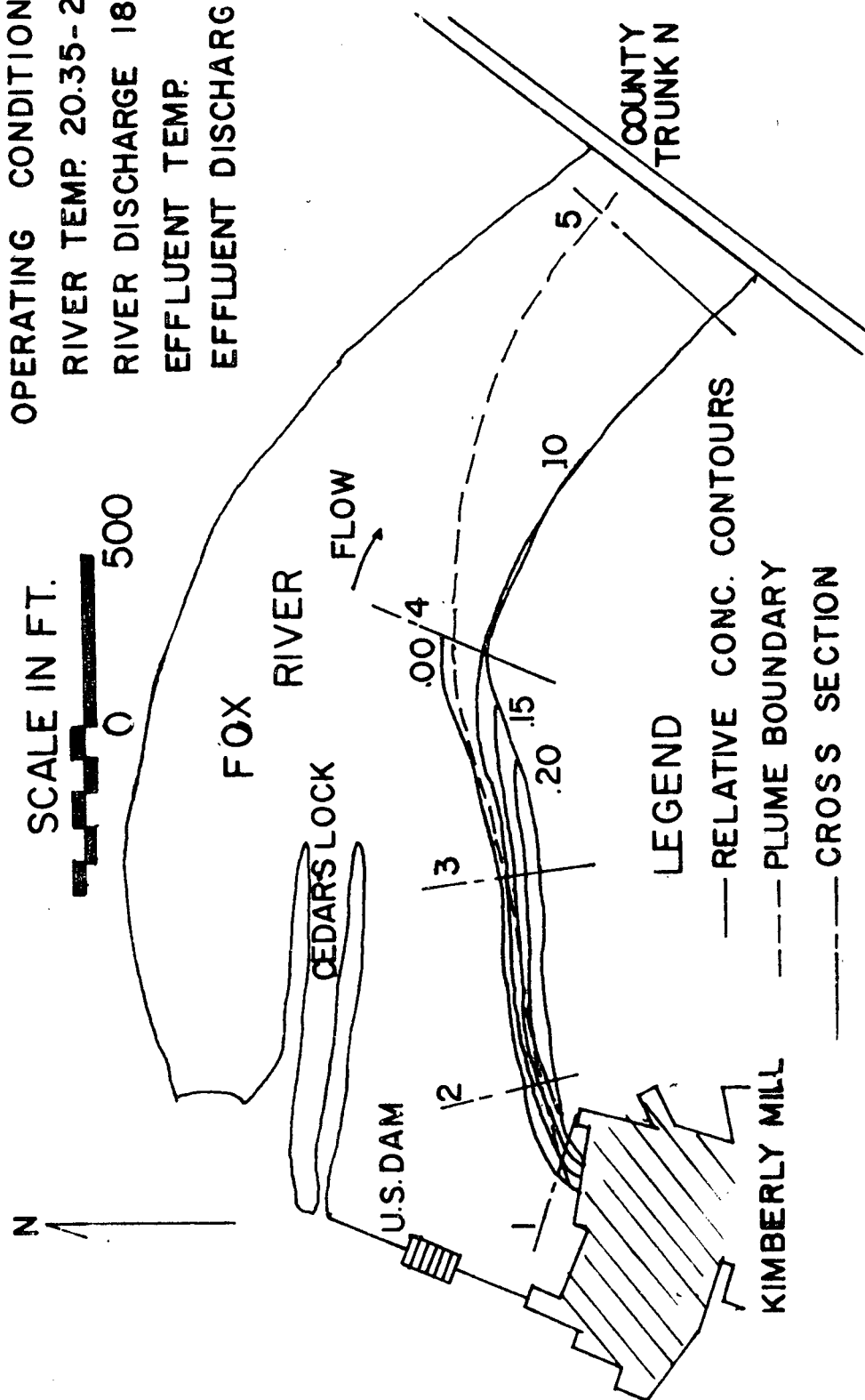


FIGURE 6 - SURFACE PATTERN OF EFFLUENT TEMPERATURE

water surface for the 27 August 1971 survey. Superimposed on the same figures are the visual boundary of the effluent discharge, obtained from 35mm color aerial photographs. The vertical distribution of velocity, temperature and dye concentration were obtained at three sections for the 11 August 1971 survey, and at five sections for the 27 August 1971 survey. Based on these observations, the boundary of the effluent discharge and the flow within this boundary have been determined at each of the eight sections. These results are shown in Figure 7. Finally, these observations have been used to compute the heat flux and dye concentration flux along the river.

Figure 8 shows a colored pattern of surface temperatures, obtained from the aerial thermal imagery of the 16 September 1971 survey. Surface temperatures and contours were obtained from the thermal imagery, using water temperatures measured simultaneously with the imagery at two locations in the river.

Based upon an analysis of these results, the following preliminary conclusions can be made:

(1) Vertical stratification of the effluent is strong near the plant due to the blending of outfall discharges of different temperatures and flows; beyond 400-500 feet from the plant the river turbulence produces complete vertical mixing over depth.

(2) Lateral spread of effluent across the river is much faster than at any of the other sites surveyed. This rapid spreading appears to result from the river bends and the downstream dam.

(3) The effluent discharge width from ground measurements is greater than that determined from aerial photographs near the outfall. Farther downstream, the widths determined by the two methods are in good agreement (see Figures 5, 6 and 7). The discrepancies in width near the outfall appear to result from unsteadiness in effluent conditions over the period of ground measurements.

(4) The effluent discharge is accurately and vividly delineated on thermal imagery and the colored pattern of surface temperatures.

C. Photographic Studies

1. Ground/Aerial Correlation of Mixing Zone Concentrations. Efforts were made to determine the extent to which the 35mm image density variations correlated with variations of water quality parameters measured at various ground truth points. Figure 9 depicts a correlation typical of the Neenah-Menasha STP mixing zone. Image density responses correlate significantly ($r = -0.95$) with variations in surficial suspended solids obtained from laboratory analysis of field samples. The strength of this suspended solids-density correlation is of course a strong function of the effluent type, as verified from preliminary

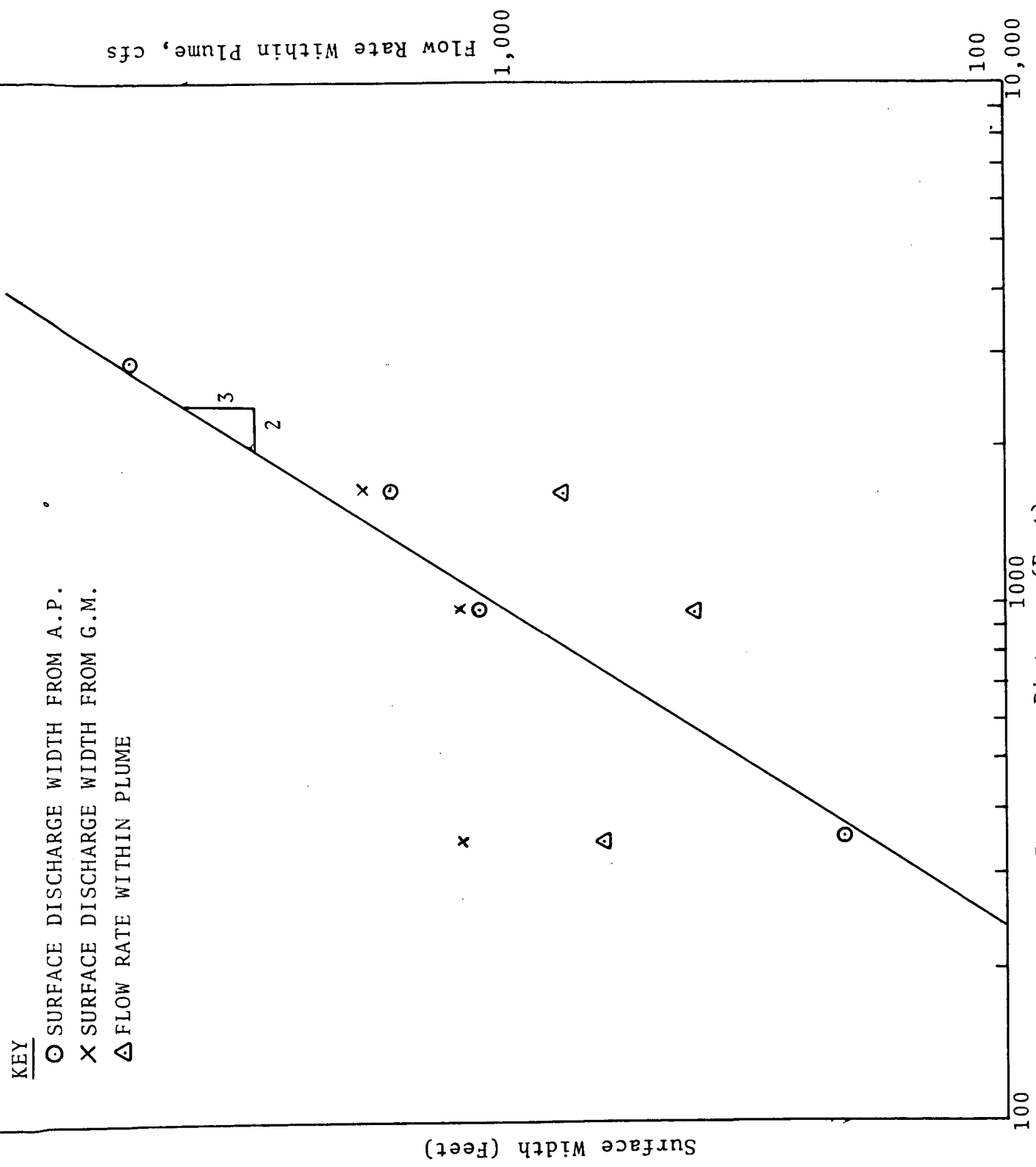


FIGURE 7 - VARIATION OF DISCHARGE SURFACE WIDTH AND FLOW WITH DISTANCE FROM OUTFALL FOR 27 AUGUST 1971, KIMBERLY MILL.

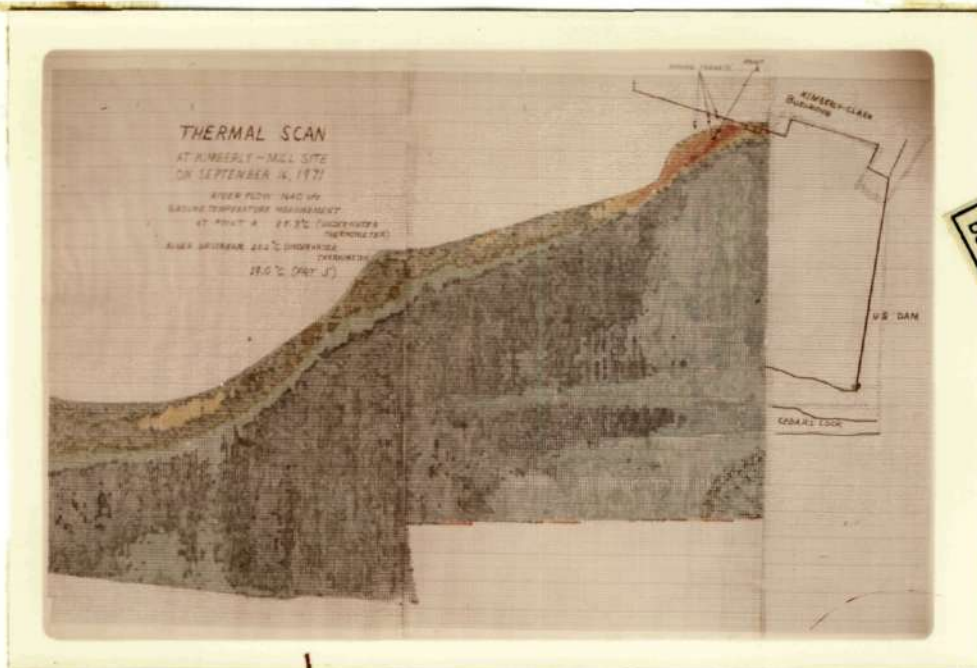


FIGURE 8

COLOR PATTERN OF SURFACE TEMPERATURES,
16 SEPTEMBER 1971 SURVEY, KIMBERLY MILL.

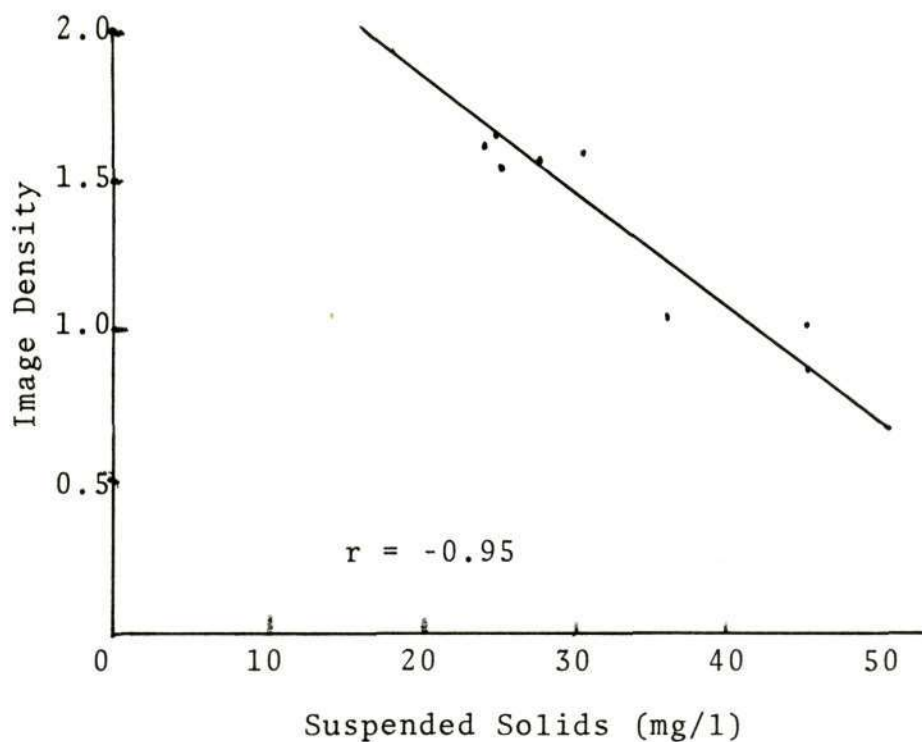


FIGURE 9

CORRELATION BETWEEN IMAGE DENSITY VARIATIONS MEASURED
ON KODAK COLOR FILM TYPE 5257 AND SUSPENDED SOLIDS
CONCENTRATIONS OBTAINED FROM LABORATORY ANALYSIS OF
GROUND SAMPLES (Neeah-Menasha STP).

ground truth at the remaining sites.

2. Development of a Methodology for Quantitative Analysis of the Mixing Zone. Analysis of the small format imagery prepared during the summers of 1970 and 1971 has suggested the practical utility of infrared emulsions in accurately depicting the surficial character of certain mixing zones. Concurrent analysis of ground data procured during the same time as the aerial imagery has documented the various relationships between surficial and volumetric plume configurations realized at each site. Knowing these quantitative links between emulsion response, surficial concentrations and volumetric concentrations, larger scale aerial studies currently are being planned for the summer of 1972 at a single site, the Kimberly-Clark Paper Mill on the Fox River. To provide increased geometric and sensitometric image fidelity, this work will entail the acquisition of 9" x 9" color IR photography concurrent with extensive ground efforts (surface and subsurface sampling). It is anticipated that the resulting aerial data will be densitized and subsequently reduced, by employing a semianalytical photogrammetric solution of chronological flight strips. The resulting film densities will be correlated with surface suspended solids concentrations, obtained from ground sampling, in a manner similar to that in Figure 9. The result of this effort will be, hopefully, a practical working methodology for quantifying the temporal and spatial behavior of similar mixing zones.

D. Mathematical Model Studies

Using the equations of mass, momentum and heat conservation, a general mathematical model has been formulated describing the concentration and velocity distributions in the mixing zone of a waste effluent discharged into a surface water body. In the initial region of the mixing zone -- where the momentum and buoyancy of the effluent play are important in the dilution process -- a one-dimensional scheme is used in which the center-line velocity, concentration and trajectory changes with distance from the outfall are predicted. In the second region of the mixing zone -- where velocity and turbulence distributions of the ambient water body govern the subsequent dilution -- a three-dimensional model is used. The mathematical model has been programmed for numerical solution; work is continuing on determination of coefficients and parameters (i.e. diffusion coefficients, entrainment coefficients, etc.) from field data and the work of others and verification of the model.

In addition, a simple three-dimensional model of the velocity and concentration distributions in the first region of the mixing zone has been developed and applied to two classical problems, the wall jet and the buoyant jet. This model is based upon an extension of Reichardt's hypothesis for lateral momentum exchange. Solutions to these two problems are being compared with experimental data and other classical models. Subsequently, this model will be applied to flows which more closely approximate the complex initial region of the mixing zone.

FUTURE PLANS

Plans for 1972-73 and beyond involve continuation and extension of the work described in the project objectives and accomplishments above. More specifically, intensive and coordinated ground and aerial surveys at the Kimberly-Clark Paper Mill on the Fox River are being planned for summer 1973. These surveys, which will be undertaken in conjunction with the Water Quality Group, will define for this mixing zone the quantitative correlation between surface and subsurface effluent suspended solids concentrations and aerial photographic response on 35mm, 70mm and 9" x 9" color and color IR formats. Correlation between suspended solids distributions and temperature distributions will also be determined.

Results of these surveys hopefully will lead to a general methodology, applicable at any site, for monitoring waste effluent concentration patterns. Further, the results and correlations from previous summers will be more intensively analyzed as to size and shape of the mixing zone and quantitative delineation of effluent concentrations and mixing patterns from aerial photographic and thermal imageries. In addition, the generalized mathematical model describing concentration and velocity patterns due to an effluent discharge into a surface water body will be applied to the prediction of mixing zone characteristics at each of the field sites. Finally, results from field measurements and laboratory and mathematical modeling work over the past three years will be synthesized into relationships for the extent of the mixing zone in terms of known or measurable river, outfall, and effluent parameters. These relationships, coupled with the methodology for quantitative delineation of waste effluent concentrations using aerial photography, will provide the basis for developing a reasonable sampling and regulation program for waste effluent discharges in cooperation with governmental agencies.

V. APPLICATION OF REMOTE SENSING TO THE LOCATION OF HYDROLOGICALLY ACTIVE (SOURCE) AREAS

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ABSTRACT

According to the source area concept, only a small fraction of a watershed is active in discharging storm runoff. The ability to locate these areas will aid in better hydrologic modeling and also will have numerous uses in water quality studies and water and land management. Since identifying these areas by field methods would be time consuming and expensive, development of remote sensing identification systems becomes necessary. In the initial phase of this study, an attempt was made to locate source areas in the Galena River (East Fork) by stereo analysis of black and white aerial photographs. Results of the analysis are very encouraging. The study has been extended to the Lowery Creek watershed in Wisconsin to investigate the visible and infrared (0.4-14 micron) region of the spectrum for developing a comprehensive remote sensing system to identify source areas. Methods of correlation will be verified in another watershed and, perhaps, will be extended to a very large watershed using ERTS-1 imagery.

SOURCE AREA CONCEPT

A. Hydrologic Factors

John D. Hewlett proposed the concept of source areas in 1961 as a better means of interpreting and explaining the various sources, pathways, and timing delays which underlie the dynamics of discharge from headwater areas. Since then, several related ideas often referred to as variable, partial, and contributing source area concepts have evolved (Hewlett, 1961; Beston and Marius, 1969; Dickinson and Whiteley, 1970; Hewlett and Nutter, 1971). Common to all these concepts is a recognition that surface and subsurface runoff is geographically concentrated at hydrologically active portions of a basin. In essence, this concept includes two simultaneous processes which together produce storm runoff:

- (1) The perennial channel system expands and extends into zones of low storage capacity and directly intercepts precipitation.

- (2) The expanding channel system is fed by subsurface flow, which may be responsible for the bulk of storm flow.

Significance. Identification of hydrologically active source areas is important in developing more accurate hydrologic information for runoff generation models and also for the following general reasons:

- (1) Water quality: Zones of high water flux will tend to rapidly lose fertilizers or pesticides to streams draining the area.
- (2) Water and land management: Identification of source areas will enable the determination of uses best suited to their physical and chemical properties.
- (3) Erosion and soil conservation: Conservation practices are most effective when applied to critical basin areas.

B. Relationship of Source Area and Runoff

Determination of Source Areas. In an attempt to locate source areas, black and white aerial photographs (approximate scale 1:12,000) covering the East Fork of the Galena River watershed were analyzed. This watershed is approximately 20.1 square miles in area, and about 80% is located in Davies County, Illinois, with the rest in Lafayette County, Wisconsin. The mirror stereoscope (Wild) was used to analyze aerial photographs. Parameters associated with source areas, such as drainage patterns, soil and vegetation types, and relief, were considered in demarcating the source area boundaries in the basin. The probable upper boundary of the source area as determined by this analysis is shown in Figure 1.

Relationship to Runoff. To verify the source area concept in general, and the method of analysis in particular, five storms in the Galena River basin were studied. Base flow was separated from each of the five storm-flow hydrographs, and the respective total runoff volume at Council Hill was determined. One such hydrograph for the storm of 16 April 1960 is shown in Figure 2. These storm runoff volumes then were compared with a simple hypothesis using the source area concept. Assuming that all precipitation that falls on the source area is discharged as storm runoff, a total runoff volume was computed by multiplying the magnitude of the source area and the total storm precipitation. A comparison of runoff volumes obtained by both methods is shown in Table 1. Figure 3 shows the deviation of values obtained by the source area concept from the perfect correlation line. It should be noted that the deviation of points is consistent with climatic conditions. Both July and August would tend to be relatively low soil moisture months, and one would expect that the size of the source area would be at a minimum. Thus the source area determined from a May photograph would over-estimate runoff volume. This plot clearly illustrates the need for a method to assess size of the source

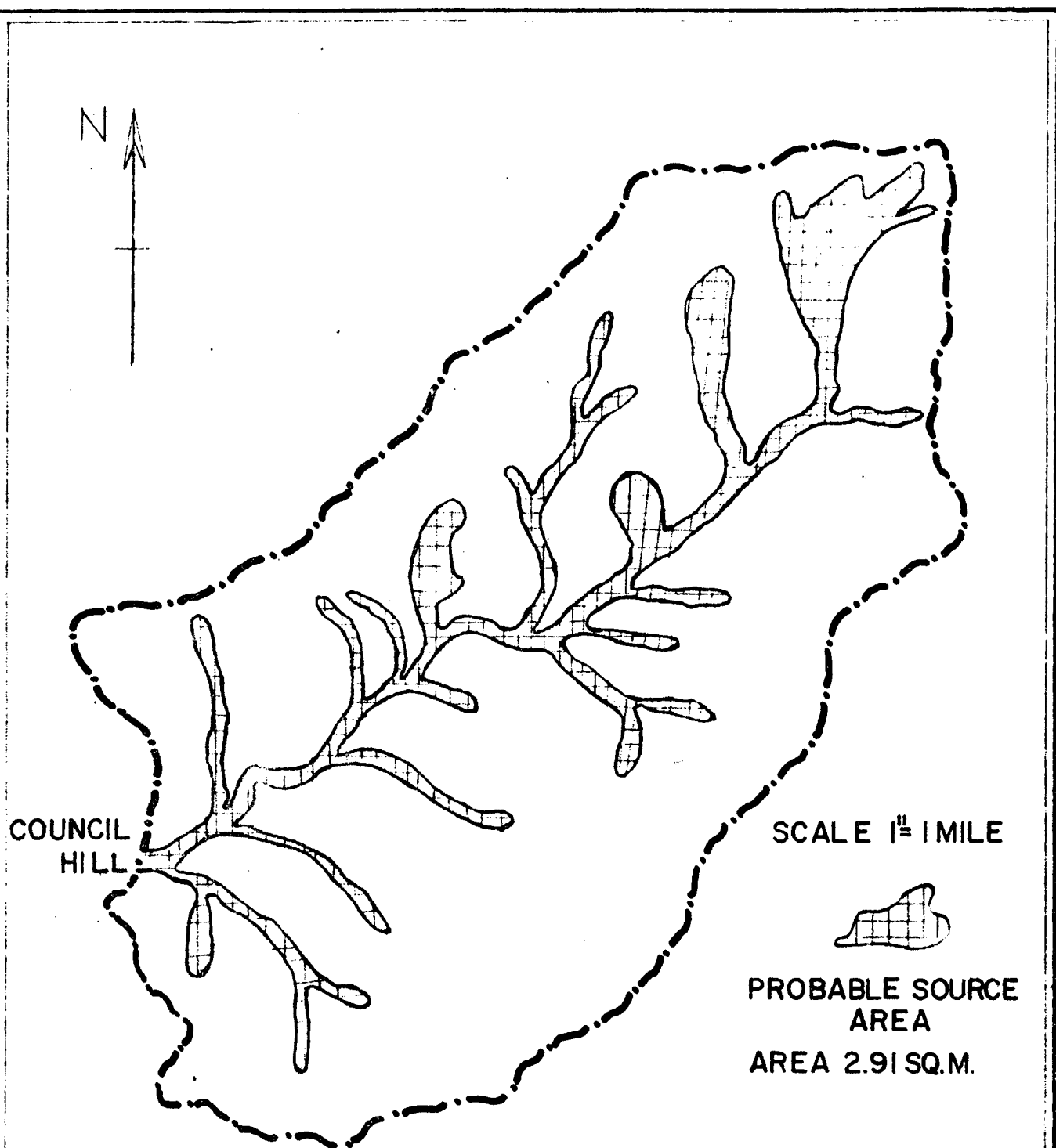


FIGURE 1

EAST FORK GALENA RIVER—COUNCIL HILL, ILL.

DRAINAGE AREA—20.1 SQ. M.

AVERAGE DISCHARGE—12.4 C.F.S. (30 YRS.)

FIGURE 2

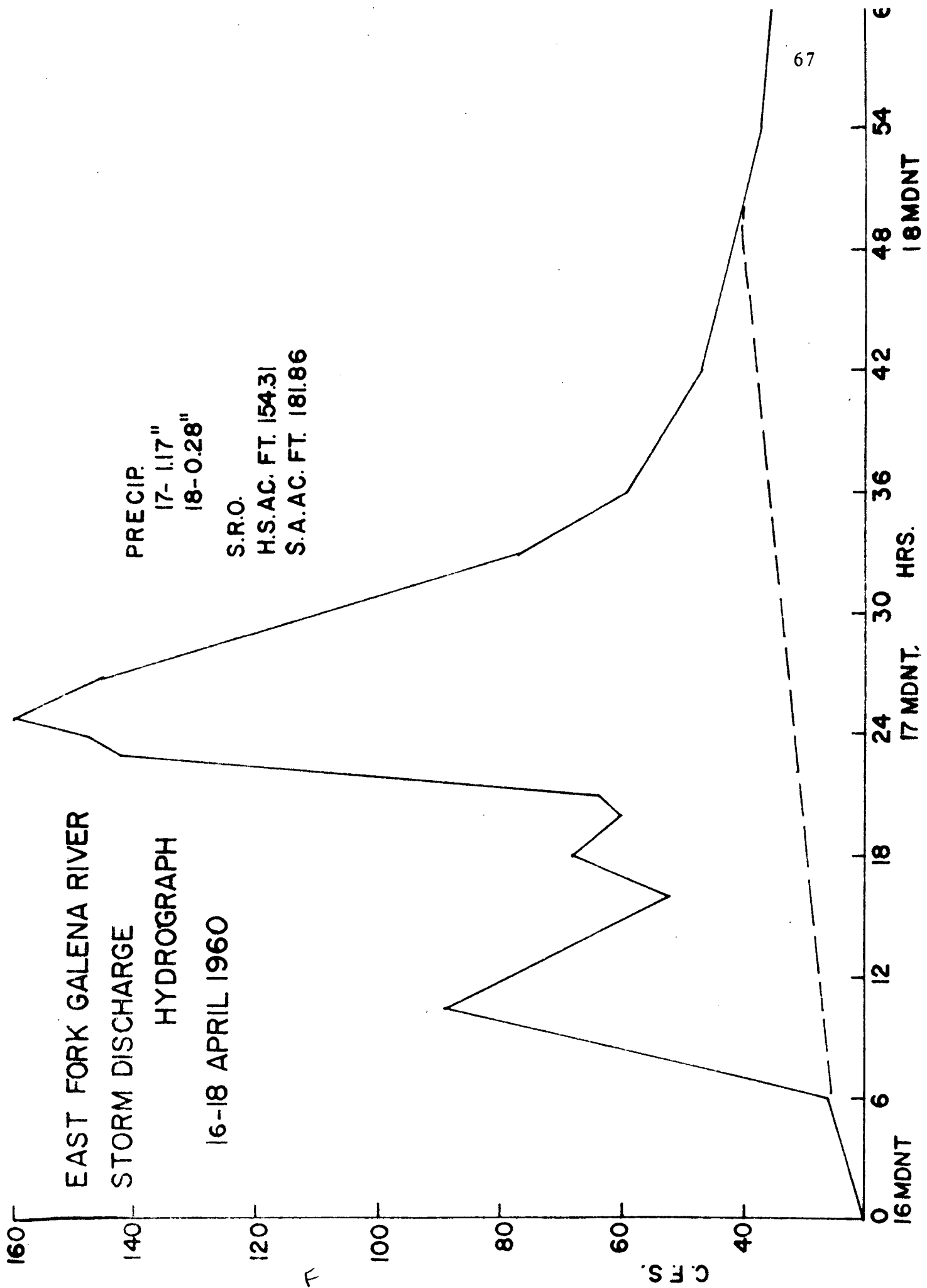


TABLE 1
COMPARISON OF TOTAL SURFACE RUNOFF
FROM HYDROGRAPH SEPARATIONS AND
SOURCE AREA CONCEPT

PERIOD	TOTAL PRECIP.	HYDROGRAPH SEPARATION AC.FT.	SOURCE AREA CONCEPT AC.FT.
23-26 October 1959	2.37	257.85	368.39
16-18 April 1960	1.45	154.31	181.86
1-3 July 1962	2.12	191.60	329.53
22-24 May 1966	2.31	421.23	359.06
25-28 June 1969	1.41	355.6	393.2

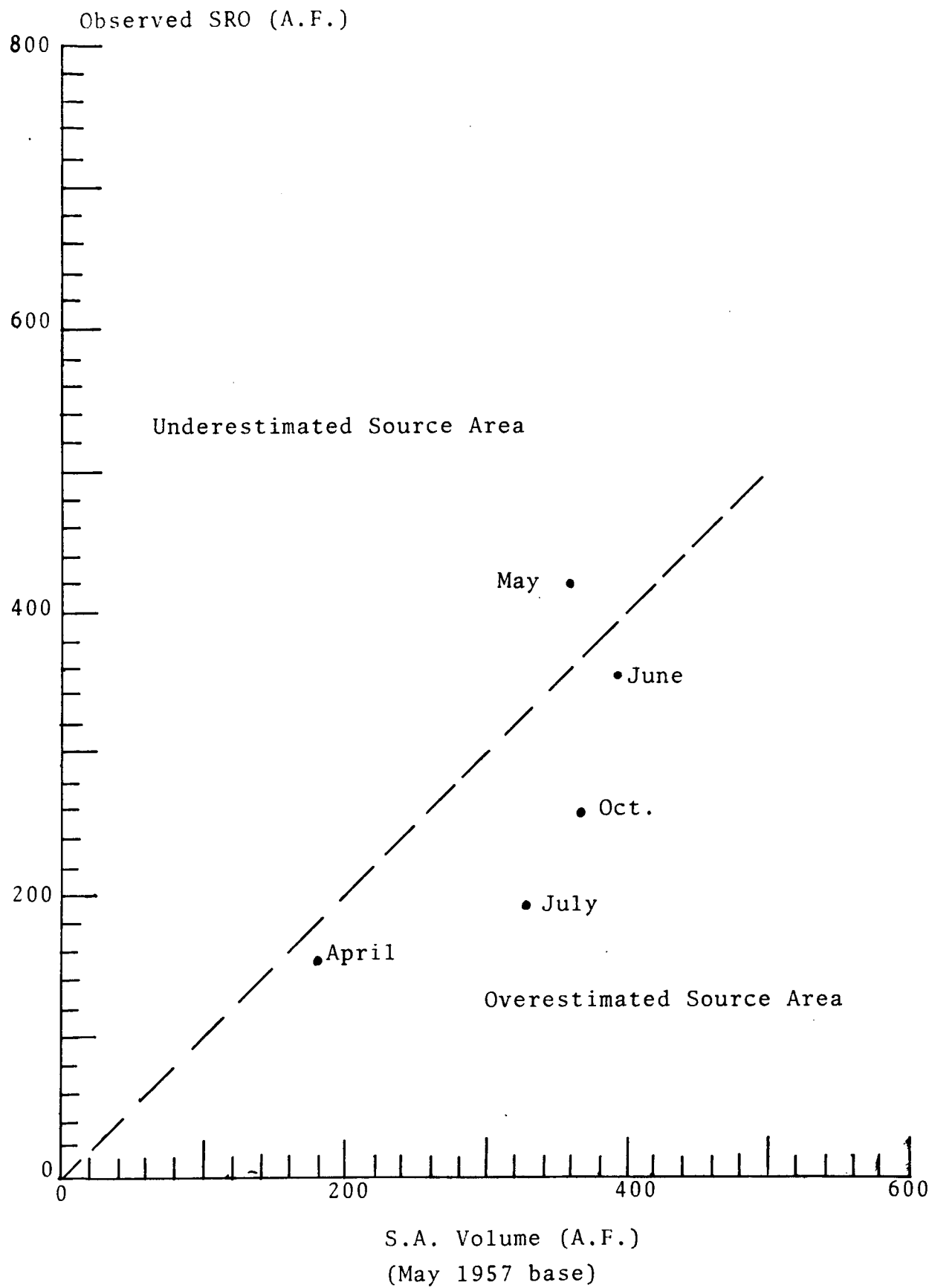


FIGURE 3

area at regular intervals.

C. Remote Sensing for Source Area Location

Sensing Considerations. Basic objective of the research project is to develop a remote sensing technique for determining the location and extent of source areas in a watershed. Closely coupled with that objective is an investigation of hydrologic properties of source areas and how they contrast with the surrounding watershed. In general, remote sensor imageries that best bring out soil moisture conditions would be used. Since the research is concerned primarily with the movement of water beneath the ground surface, it seems appropriate to use imageries of longer wave lengths (thermal 8-14 m, radar 1mm-3m). Huff and Pilgrim (1968) found that infrared imagery could be used to detect pathways for movement of subsurface water. Also, Coker (1969) and Stephenson (1970) found thermal imagery to be a valuable tool in geo-hydrological studies.

D. Future Research Plans

Remote Sensing. Lowery Creek, located approximately 40 miles west of Madison, has been chosen as the watershed for a comprehensive study. An early priority is a series of flights with aircraft equipped to obtain photographic (black and white, color, and color IR) and thermal imageries. Photographic and thermal sensing would be repeated in the four consecutive days immediately following a major rainfall event to determine the dynamic aspect of source areas. These operations probably would be conducted in early spring or late autumn as soon as possible after a major rainstorm, or perhaps at the end of the spring snowmelt.

Ground Truth Instrumentation. In a simultaneous operation, ground truth would be obtained for stream flow, soil moisture content and ground water seepage. Instruments will be installed to determine precipitation amounts, depth variation of soil moisture with time, and stream discharge. Two of the most important parameters, saturated thickness of aquifers and depth of the impervious bottom, may have to be obtained by resistivity or seismic methods if the more popular methods are not amenable to the situation.

Correlation and Verification. Knowing the soil moisture variation along a pre-selected traverse in the source area and in the runoff plots, the remote sensing imagery will be correlated to the observed runoff areas, thereby monitoring the shrinkage or expansion of the source area with time. Following the development of a suitable remote sensing system to identify source areas in the Lowery Creek watershed, the applicability of this technique will be verified in another watershed of larger magnitude. If verification is successful, it should be possible to apply the techniques developed in this research project to large river basins using ERTS-1 imagery.

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VI. APPLICATION OF REMOTE SENSING TO AQUATIC ECOSYSTEMS ANALYSIS

A. MACROPHYTE PRODUCTIVITY IN LAKE WINGRA

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BACKGROUND

As a part of the International Biological Program's intensive ecosystem studies, many Wisconsin disciplines have been involved in an effort to model the aquatic ecosystem of Lake Wingra. Work of the past months has resulted in development of a production model for Myriophyllum spicatum L., the lake's most important aquatic plant. Remote sensing techniques are being used to provide some inputs for this model. Procedures have been developed that utilize the data available from aerial photography to give good biomass estimates with greater efficiency than traditional methods.

INTERPRETATION OF PHOTOGRAPHY

The aerial photography used is 35mm color and color IR from altitudes of 2,500 to 7,000 feet. Extensive ground truth was conducted during the past season to correlate photographic images with the vegetational attributes of Lake Wingra. The major plant communities were investigated for composition and general location, while seasonal phenology was monitored. Exact locations of vegetational boundaries were marked by 1.2 meter square white plywood panels that are easily located in the photographs.

The following unique communities can be differentiated in aerial photographs taken during the 1971 season:

M. spicatum - Potamogeton; typical of shallow water areas

Dense M. spicatum; pure stand of nearly solid growth

Sparse M. spicatum; clumpy growth patterns usually in deeper water areas

Nuphar-Nymphaea; water lilies

Ceratophyllum demersum; found often in areas of sparse
M. spicatum

Oedogonium sp.; a mat of a filamentous green algae that
overgrows M. spicatum beds in the western part of the
lake

Color IR was found superior for community recognition in locations where vegetation is emergent or where the submerged stems are within 6 to 8 inches of the water surface. Agfachrome provided the best information for locations in which plant growth remained well below the surface.

FIELD WORK AND MAPPING

Lake Wingra vegetational maps were prepared from aerial photographs taken three times during July and August. Figure 1 is a portion of the map drawn from 10 August 1971 data. The slides or bulk film were projected onto a screen, and the image was rectified by rotating the screen to match the projections with the shoreline drawn on mylar. Growth areas for the various plant communities were measured from the maps using a planimeter.

Extensive field sampling of M. spicatum was conducted during the 1970 season, and the results were used for making some of the estimates for the 1971 season. The 1971 sampling was conducted during August and September, and the results were used for making biomass estimates of M. spicatum and Oedogonium for that period. M. spicatum was sampled using one meter square quadrats located by a stratified random design. One set of 20 samples was taken from each of the two major M. spicatum community types as interpreted from the photography. Ash-free dry weights were determined. The algae mat was sampled on three occasions, using .1 meter square units located by a stratified random design. Dry weights were determined.

RESULTS

Total Myriophyllum and Nuphar-Nymphaea biomass figures for the first two 1971 sampling periods are shown in Table 1. The first period estimates of Myriophyllum were made from photographs taken 14 July 1971 and from 1970 field sampling data. The second period estimates utilized field sampling data collected in 1971. A comparison of data collected with and without the use of aerial photography is shown in Table 2. The low total biomass figure for the July 1971 period is due, in part, to a reduction of early growth in some parts of the lake where a robust early growth normally occurs. A substantial reduction in size of the confidence interval was noted for the 10 August 1971 results. This is due to use of photographs to locate sampling areas within sections of relatively homogenous plant growth. Biomass data for the green algae Oedogonium are shown in Table 1. Biomass totals were calculated for 8 and 17 August and 8 September, and they indicate that peak growth should have

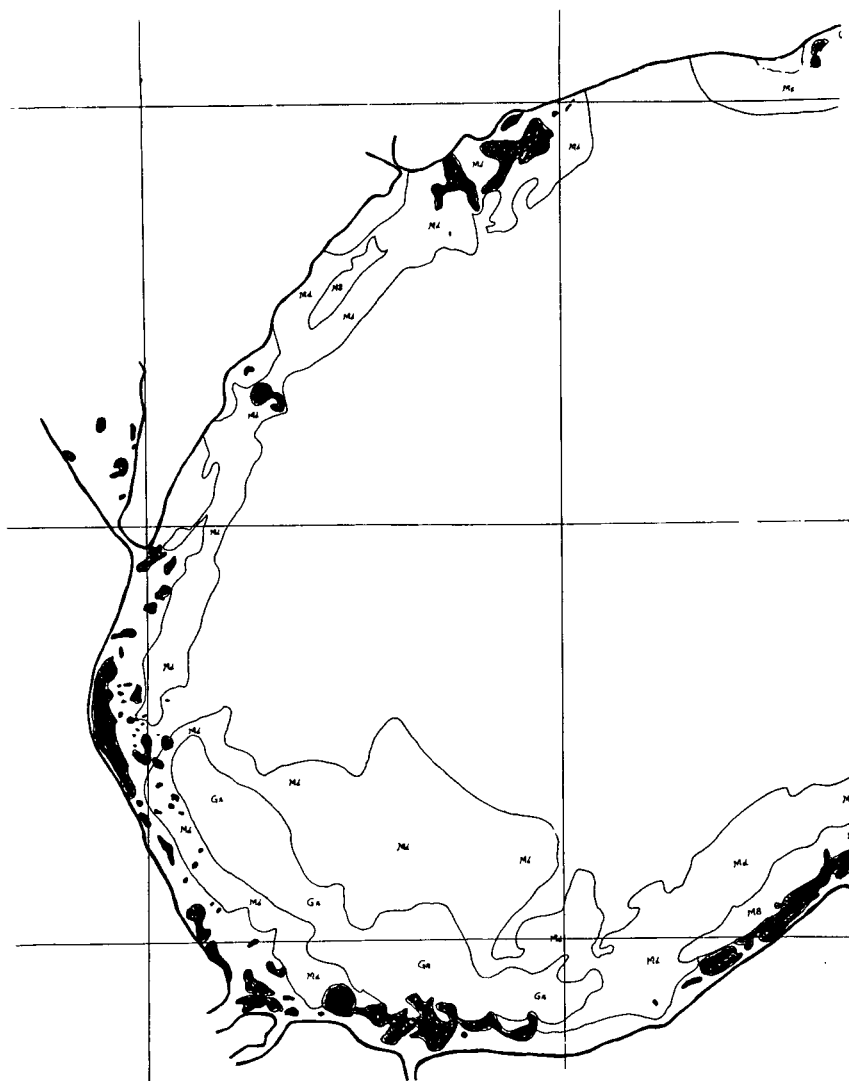


FIGURE 1

A portion of the Lake Wingra vegetational map of 10 August 1971. Communities shown: shaded area - Nuphar and Nymphaea, Md - dense Myriophyllum spicatum, Ms - sparse M. spicatum, GA - Oedogonium algal mat, MB - marl bottom nearly devoid of vegetation.

TABLE 1
1971 BIOMASS ESTIMATES FOR
MAJOR MACROPHYTE COMMUNITIES OF LAKE WINGRA

	14 July	10 August		
<u>M. spicatum</u>				
Dense growth:				
Growth area (m ²)	28,350	103,400		
Average biomass (gm/m ²)	572	422		
Total biomass (kg)	16,210	43,600		
Sparse growth:				
Growth area (m ²)	121,100	253,300		
Average biomass (gm/m ²)	184	215		
Total biomass (kg)	22,230	54,500		
<u>Nuphar-Nymphaea</u>				
Growth area (m ²)	21,800	18,800		
Area biomass (gm/m ²)	183	183		
Total biomass (kg)	3,897	3,448		
<u>Oedogonium</u>				
	14 July	8 August	17 August	8 September
Growth area (m ²)	17,000	16,400	16,400	16,400
Average biomass (gm/m ²)	--	87.2	70.7	42.4
Total biomass (kg)	--	1,430	1,160	690

TABLE 2
COMPARISON OF HARVEST METHOD AND REMOTE SENSING (1971)
WITH HARVEST METHOD ALONE (1970)
 (Results for Myriophyllum spicatum L.)

	<u>6-10 July 1970</u>	<u>14 July 1970</u>
Total biomass (kg)	65,076	38,440
95% CI (kg)	44,541-76,904	23,062-53,814
Time required (hours)	130	20
	<u>3-7 August 1970</u>	<u>10 August 1970</u>
Total biomass (kg)	94,600	97,000
95% CI (kg)	57,700-120,600	77,100-118,760
Time required (hours)	130	60

been in late July or early August. Development of this algal mat during the 1972 season is being monitored from its first appearance in June.

FUTURE PLANS

During the 1972 season bi-weekly aerial photographic missions are being flown over Lake Wingra, and limited field sampling is being conducted. An excellent seasonal record of lake vegetation should result. An effort will be made to correlate densitometer analysis with the community characteristics noted visually and with the progressive encrustment that affects the Myriophyllum plants. Several other Madison area lakes also will be photographed, and the applicability of the Wingra methods will be tested on other aquatic communities. The possibility of using remote sensing techniques to provide an initial estimate of lake eutrophication will also be examined.

B. REMOTE SENSING OF ALGAL BLOOMS

Principal Investigator:

William J. Woelkerling, Assistant Professor, Department of Botany

BACKGROUND

Results of laboratory studies in an earlier phase of this investigation, with two blue-green and two green algae, indicate that remote sensing techniques may have potential value in obtaining qualitative and quantitative information on algal blooms in lakes and rivers. In particular, the results demonstrate that blue-green algae and green algae differ in their spatial reflectance characteristics, and these differences may be detectable in the field by remote sensing techniques.

FIELD INVESTIGATIONS

Two lakes in the Madison, Wisconsin, area (Mendota and Wingra) were selected for study. Both experience algal blooms which may involve blue-green or green algae and which occur most frequently in summer and fall.

Each lake is monitored by a ground truth team for development of algal blooms; affected areas are simultaneously sampled from the ground and air. Ground data includes water chemistry and biological features (extent of bloom, standing crop, species present). Algae samples are brought to the laboratory for densitometer analysis, and vouchers are prepared. Aerial data is obtained with 35mm color and color IR film.

Field work was initiated in mid-June 1972 and continued on a weekly basis throughout the season.

POTENTIAL APPLICATIONS

Several potentially valuable applications of remote sensing techniques are being assessed during the course of this study. One application involves the use of such techniques in determining qualitative and quantitative characteristics of particular algal blooms. Such data, if available by the time-saving techniques of remote sensing, could lead to a better understanding of the biology of algal blooms.

A second application involves large-scale monitoring of recreational lakes and water supplies for algal blooms. If remote sensing techniques show promise, it may be possible to monitor extensive areas and report to the public which lakes in their area are currently experiencing algal blooms and which are free of such disturbances. Furthermore, such information is potentially useful to people concerned with purifying water for human consumption.

VII. LIST OF PUBLICATIONS RESULTING FROM
THE UNIVERSITY OF WISCONSIN REMOTE SENSING PROGRAM,
1971-1972

A. NEW PUBLICATIONS

1. Gramms, Lorne C., and William C. Boyle, A Literature Review of Remote Sensing for Water Quality, University of Wisconsin, Remote Sensing Report Series, Number 7, October 1971.
2. Kiefer, Ralph W., Effects of Date of Photography on Airphoto Interpretation Using Color and Color Infrared Films, University of Wisconsin, Remote Sensing Report Series, Number 9, Reprinted from the Proceedings of the 1970 International Symposium on Photography and Navigation, Columbus, Ohio, May 1970.
3. Kiefer, Ralph W., Sequential Aerial Photography and Imagery for Soil Studies, University of Wisconsin, Remote Sensing Report Series, Number 10, January 1972.
4. Adams, M.S., M. McCracken and K. Schmidt, Preliminary Results of Measurements of Primary Productivity of Aquatic Macrophytes and Periphyton in Lake Wingra During 1970-1971, University of Wisconsin, Memo Report #71-18, Eastern Deciduous Forest Biome, International Biological Program, October 1971.
5. Scarpace, F. L., and T. Green, The Use of a Thermal Scanner in the Remote Sensing of Water Pollution, University of Wisconsin, Remote Sensing Report Series, Number 11, April 1972.
6. Scherz, J. P., Final Report on Infrared Photography Applied Research Program, University of Wisconsin, Remote Sensing Report Series, Number 12, June 1972.
7. Rinehardt, G.L., and J.P. Scherz, A 35mm Aerial Photographic System, University of Wisconsin, Remote Sensing Report Series, Number 13, April 1972.
8. Yeske, L., T. Green, F. Scarpace and R. Terrell, Current Measurements in Lake Superior Using Aerial Photogrammetric Techniques: A Preliminary Report, University of Wisconsin, Remote Sensing Report Series, Number 14, April 1972.
9. Tuerkheimer, F. M., Legal Aspects of Water Pollution Detection Through Remote Sensing, University of Wisconsin, Remote Sensing Report Series, Number 15, April 1972.

10. Green, T., T. Mackenzie, S. Roffler, F. Scarpance, C. Sundby and T. Keating, The Point Beach Thermal Plume, University of Wisconsin, Remote Sensing Report Series, Number 16, April 1972.
11. Scarpance, F.L., and T. Green, On Rapid Changes and Periodic Temperature Structure in Thermal Plumes, University of Wisconsin, Remote Sensing Report Series, Number 17, June 1972.
12. Scarpance, F.L., and P.R. Wolf, Convenient Atmospheric Refraction Equations, University of Wisconsin, Remote Sensing Report Series, Number 18, August 1972.
13. Jacques, J., J.R. Villemonte and J.A. Hoopes, Hydraulic Model Study of the Condenser Cooling Water Discharge From the Weston Power Plant on the Wisconsin River, University of Wisconsin, Remote Sensing Report Series, Number 19, August 1972.

B. PREVIOUS PUBLICATIONS

14. Adams, M.S., Productivity of Macrophytes in Lake Wingra, University of Wisconsin, Department of Plant Ecology, September 1970. (Publication pending)
15. Gramms, L.C., and W.C. Boyle, Reflectance and Transmission Characteristics of Selected Green and Blue-Green Unialgae, Proceedings, 7th International Symposium on Remote Sensing of the Environment, 17-21 May 1971, #10259-1-X, Ann Arbor, Michigan; Water Research, 6, 1972; University of Wisconsin, Remote Sensing Report Series, Number 5, July 1971.
16. Kiefer, R.W., and J.P. Scherz, Aerial Photography for Water Resource Studies, Journal of Surveying and Mapping, ASCE, 97, #SU2, Proc. Paper 8545, November 1971, pp. 321-333; University of Wisconsin, Remote Sensing Report Series, Number 6, August 1971.
17. Scherz, J.P., Monitoring Water Pollution by Use of Remote Sensing Techniques, University of Wisconsin, Remote Sensing Report Series, Number 3, April 1971; Reprinted from the ASCE National Water Resources Meeting, Tuscon, Arizona, January 1971.
18. Scherz, J.P., and A.R. Stevens, An Introduction to Remote Sensing for Environmental Monitoring, University of Wisconsin, Remote Sensing Report Series, Number 1, August 1970.

19. Scherz, J.P., Remote Sensing - A New Tool in Water Resources Management, Presented at the 24th Midwestern States Flood Control and Water Resources Conference, Milwaukee, Wisconsin, 21-22 May 1969.
20. Stephenson, D.A., Evaluation of Thermal Imagery, Normal and Infrared Color Photography for Solid Waste Disposal Studies, University of Wisconsin, Department of Geology and Geophysics, September 1970. (In press)
21. Milfred, C.J., D.E. Parker and G.B. Lee, Remote Sensing for Resource Management and Flood Plain Delineation, Presented at the 24th Midwestern States Flood Control and Water Resources Conference, Milwaukee, Wisconsin, 21-22 May 1969.
22. Niemann, B.J., M.M. McCarthy and S.A. Dunn, Satellite Sensing, Landscape Architecture, pp. 42-47, October 1970.
23. Parker, D.E., and C.J. Milfred, 1970, Delineation of a Flood Plain by Interpretation of Panchromatic and Color Aerial Photographs, Photogrammetric Engineering (accepted for publication).
24. Parker, D.E., 1970, Use of Remote Sensing Techniques for Soil Mapping in Northern Wisconsin Landscapes, University of Wisconsin, Department of Soil Science, Ph.D. Thesis.
25. Hofmeister, G.J., 1970, Reflectance Characteristics of Oils on Water, University of Wisconsin, Department of Civil and Environmental Engineering.
26. Van Domelen, J.F., Determination of Oil Film Depths for Water Pollution Control, University of Wisconsin, Remote Sensing Report Series, Number 4, June 1971.
27. Stamm, A.J., and T.H. Vonder Haar, Atmospheric Effects on Remote Sensing, University of Wisconsin, Space Science and Engineering Center, Final Project Report, 15 August 1970.
28. Kiefer, R.W., and J.P. Scherz, Applications of Airborne Remote Sensing Technology, Journal of the Surveying and Mapping Division, ASCE, Vol. 96, #SU, Proc. Paper 7225, April 1970, pp. 57-80.
29. Scherz, J.P., et al., Photographic Characteristics of Water Pollution, Photogrammetric Engineering, January 1969.
30. Scherz, J.P., End of Year Report on Special Aerial Photography Research Project, Wisconsin Water Resources Committee of State Agencies, December 1968.

31. Stevens, A.R., Pre-Visual Detection of Dutch Elm Disease, University of Wisconsin, Department of Civil and Environmental Engineering, Ph.D. Thesis, publication pending (In press).

VIII. WORKING SEMINARS ON THE REMOTE SENSING
OF THE ENVIRONMENT, 1971-1972

<u>DATE</u>	<u>TOPIC</u>	<u>SEMINAR LEADER</u>
1 Oct. 1971	"NCAR Flights"	Dr. F.L. Scarpace Dr. R.E. Terrell
8 Oct. 1971	"Water Quality"	Dr. J.P. Scherz
15 Oct. 1971	"Mixing Zone"	Dr. J.R. Villemonte Dr. J.A. Hoopes
22 Oct. 1971	"Mixing Zone"	Mr. T.M. Lillesand
29 Oct. 1971	"Lowery Creek"	Prof. B.J. Niemann
5 Nov. 1971	"Blue-Green Algae and Water Quality"	Dr. W.C. Boyle Mr. L.C. Gramms
12 Nov. 1971	"Keweenaw"	Prof. T. Green
19 Nov. 1971	"Point Beach"	Prof. T. Green
3 Dec. 1971	"Remote Sensing from Earth Orbit"	Dr. R.W. Kiefer
10 Dec. 1971	"ERTS Satellite"	Prof. B.J. Niemann
7 Jan. 1972	"Proposed Objectives of the ERTS Principal Investigators"	Prof. J.L. Clapp
14 Jan. 1972	"Atmospheric Corrections for Airborne Radiation Thermometers"	Mr. P. Twitchell
4 Feb. 1972	"ERTS Data Flow"	Prof. J.L. Clapp Prof. B.J. Niemann
11 Feb. 1972	4 Feb. continued	
18 Feb. 1972	"Remote Sensing of Macrophytes on Lake Wingra"	Mr. T. Gustafson
25 Feb. 1972	"Some Reflections on Lake Wingra Circulation"	Prof. J.A. Hoopes
3 Mar. 1972	"Inventory System for ERTS and Remote Sensing Data"	Mr. E. Kuhlmeier Mr. R. Singh
10 Mar. 1972	"Bottom Effects in Remote Sensing for Water Quality"	Prof. J.P. Scherz
24 Mar. 1972	"NCAR Flights"	Dr. R.E. Terrell
21 Apr. 1972	"Sequential Aerial Photography and Imagery for Soil Studies"	Dr. R.W. Kiefer
28 Apr. 1972	"Special Photographic Processes for Remote Sensing"	Mr. J. Hall
5 May 1972	"Water Pollution"	Mr. F.M. Tuerkheimer
12 May 1972	"Algae and Remote Sensing"	Dr. W. Woelkerling
19 May 1972	"Some Techniques of Analysis of Thermal Scanning Imagery"	Dr. F.L. Scarpace